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THE NATURE OF ACOUSTIC RESPONSE: THE RELATION BETWEEN STIMULUS INTENSITY AND THE MAGNITUDE OF COCHLEAR RESPONSES IN THE CAT *

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In a previous publication we have presented results on the relation between sound intensity and the magnitude of cochlear responses in the guinea pig.[1] This article deals similarly with responses from the cochlea of the cat. Results on the cat have previously been reported by Davis and his collaborators [2] and by Covell and Black;[3] these contributions will be considered in the final section of this paper.

APPARATUS AND PROCEDURE

The animal was maintained under deep urethane anesthesia. The auditory bulla was approached from the ventral side through an incision in the throat, and opened to expose the round window.[4] A silver-foil electrode was placed in contact with the

* This investigation was aided by a grant from the National Research Council.

[1] E. G. Wever and C. W. Bray, The nature of acoustic response: the relation between sound intensity and the magnitude of responses in the cochlea, *J. Exper. Psychol.*, 1936, **19**, 129–143.

[2] H. Davis, The electrical phenomena of the cochlea and the auditory nerve, *J. Acoust. Soc. Amer.*, 1935, **6**, 205–215; and references there cited.

[3] L. J. Black and W. P. Covell, A quantitative study of the cochlear response, *Proc. Soc. Exper. Biol.*, 1936, **33**, 509–511; Covell and Black, The cochlear response as an index to hearing, *Amer. J. Physiol.*, 1936, **116**, 524–530.

[4] For a description and illustration of this exposure, see W. Hughson and S. J. Crowe, Experimental investigation of the physiology of the ear, *Acta oto-laryngol.*, 1933, **18**, 296 *ff.* An early account of this operation was given by R. Heidenhain, Ueber

round-window membrane, and a second, indifferent electrode was inserted in muscle tissue at the edge of the incision.

The animal was placed in a sound-proof, electrically shielded room, with the meatus of the ear at a standard distance of 2.5 cm from a tube through which tonal stimuli were delivered. The tones were generated by a loudspeaker actuated by currents from an audio-oscillator. Electric filters were used to purify the oscillator currents, and attenuators to control their intensity. The stimulating apparatus was calibrated over the range from 100 to 10,000~ by means of a condenser microphone, which was placed at the position normally occupied by the ear of the animal. On the basis of this calibration the intensity of the stimuli was known in absolute units of sound pressure (bars = dynes per sq. cm, rms).

The electrical potentials picked up by the electrodes were amplified and led to one of two recording instruments. For general measurements the waves of response were observed on a cathode-ray oscillograph. In some of the experiments, voltage readings were made by means of a wave analyzer (General Radio 636 A). This instrument is essentially a vacuum-tube voltmeter that may be adjusted to record any desired single frequency from 20 to 16,000~. Since the selectivity of the instrument was such that signals 30~ away from the setting were reduced 40 db., it was possible to measure the fundamental component of the response in practical isolation.

The amplifier and both recording instruments were calibrated so that the electrical effects as picked up at the round window could be determined in absolute units (microvolts).

The procedure consisted of the presentation, at various intensities, of a number of tones within the animal's range of sensitivity. The intensities were varied in steps of 5 or 10 db. from the smallest that gave a measurable response to the greatest available. When the cathode-ray oscillograph was used, the measurements gave the maximum amplitude of the response wave, from which the effective (rms) values of response were calculated on the assumption that the wave was sinusoidal in form. Only at the highest intensities were the distortions of wave form great enough to impair the accuracy of this procedure.[5] When the wave analyzer was used, the measurements gave rms values of the fundamental frequency, regardless of the form of the wave.

Since the calibration of the stimulating apparatus was limited to the range of 100 to 10,000~, tones above that range were used only for relative measurements, and to explore the upper limits of response. The highest tone for which responses were observed in the cat was 30,000~ as compared with 25,000~ in the guinea pig. It should be borne in mind that these limits are in part a function of the sound intensities available and the conditions of observation; they have relative but not absolute significance.

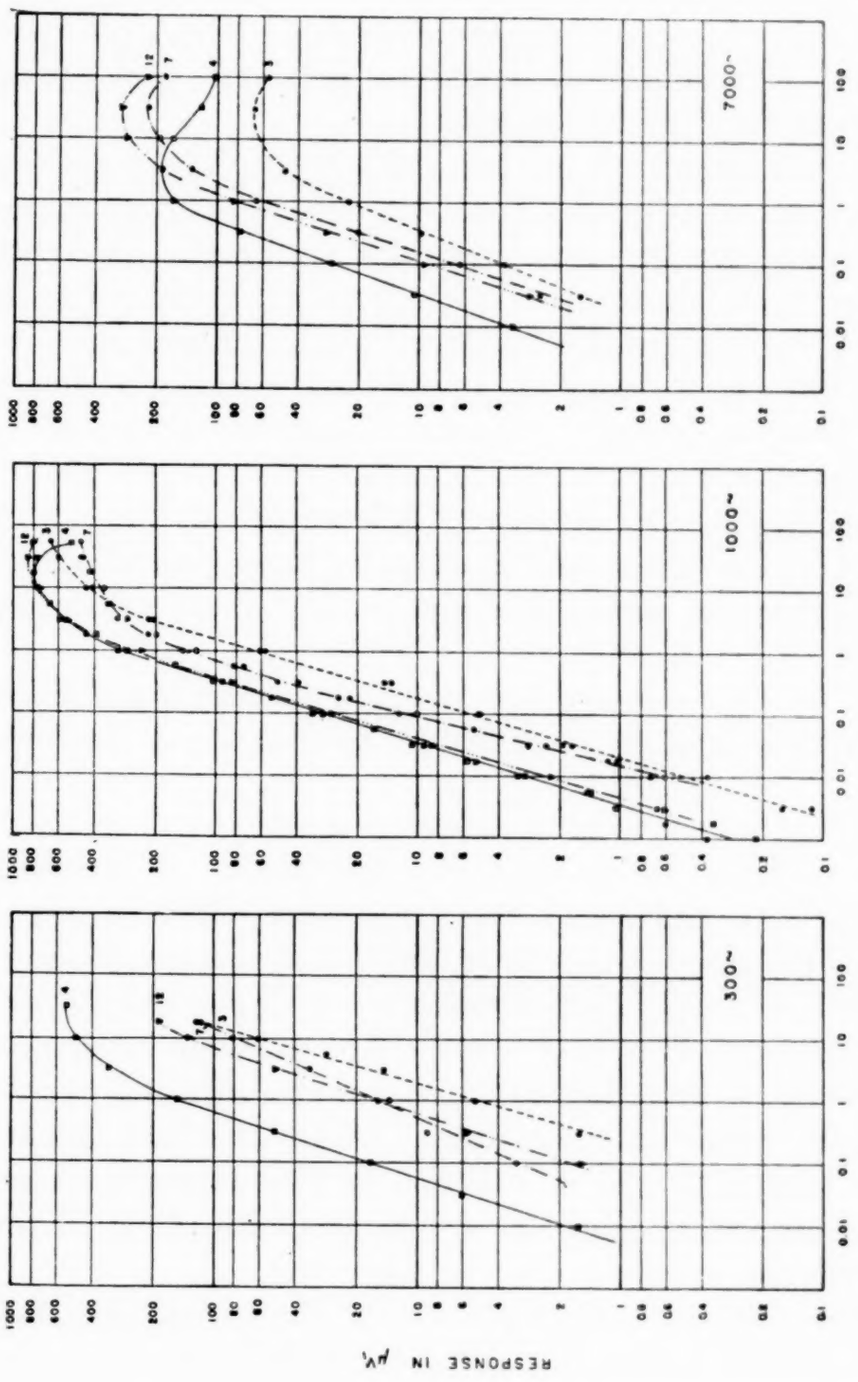
Experiments were carried out with 12 cats, sometimes on both ears, so that they numbered 16 in all.

Results

The results defined the relation between sound intensity and the magnitude of electrical responses in the cochlea for tones from 100 to 10,000~. Since the general form of this relation varies but little between tones and from one animal to another, only a few of the curves will be given.

secretorische und trophische Drüsennervern, *Pflügers Arch. f. d. ges. Physiol.*, 1878, **17**, 16–17.

[5] These distortions were not present in the stimulus, but arose in the ear.



FIGS. 1–3. Intensity functions, showing the relation between sound intensity and cochlear response for 300, 1000, and 7000~. The numbers at the top of the curves designate particular animals.

Figures 1–3 show intensity functions obtained from four animals with the tones 300, 1000, and 7000~. In each figure, sound intensity in bars is indicated on the abscissa and response in microvolts (μv.) on the ordinate. Both scales are logarithmic. The observed points are indicated, and curves are drawn as fitted by inspection.

The curves are straight for low and intermediate intensities of sound, and usually are bent downward at their upper portions where the stimulus intensities are great. Probably the curves that fail to show such bending would do so if sufficiently high intensities had been used.[6] There are considerable differences among the animals in the level of response at which bending becomes prominent, and in the amount of bending that occurs.

The curves show moderate differences of slope. In general, those for the lower frequencies have greater slopes than those for the higher frequencies, but there are many exceptions.

Curves which are straight on double logarithmic scales are power functions, and are expressed by an equation of the form

$$E = kP^a,$$

where E = electrical potential in microvolts, P = sound pressure in bars, and a and k are constants. The exponent a expresses the slope of the curve, and k is a measure of sensitivity. If $a = 1$, the function reduces to a simple linear form.

The curves of Figs. 1–4 are straight at their lower and middle portions, and therefore are power functions over a considerable range of intensities. Most of them depart markedly from this type of function at high intensities, and assume a form that suggests a serious overloading of the acoustic system.

The slopes of the straight portions of the curves vary, but are in the general region of 1. For example, in Figs. 1–3 the slopes for No. 12 for 300~ and No. 4 for 1000~ are nearly equal to 1, those for No. 3 at 300~ and Nos. 3, 7, and 12 at

[6] See E. G. Wever, C. W. Bray, and C. F. Willey, The response of the cochlea to tones of low frequency, *J. Exper. Psychol.*, 1937, **20**, 341 *ff.*; and Covell and Black, *Amer. J. Physiol.*, 1936, **116**, 525 *ff.*

1000~ are slightly greater than 1, while the others are somewhat less than 1.

The efficiency of the ear as an electro-acoustical device is proportional to the ratio of output in microvolts to input in bars. This ratio is constant only for functions with a slope of 1; for other functions it varies with intensity. A slope below 1 means that efficiency becomes less, and one above 1 that it becomes greater, as the level of intensity is raised. Beyond the straight portions of the curves the efficiency declines rapidly.

Differences in sensitivity are shown by the location of the curves with respect to the abscissa. In Fig. 1, for example,

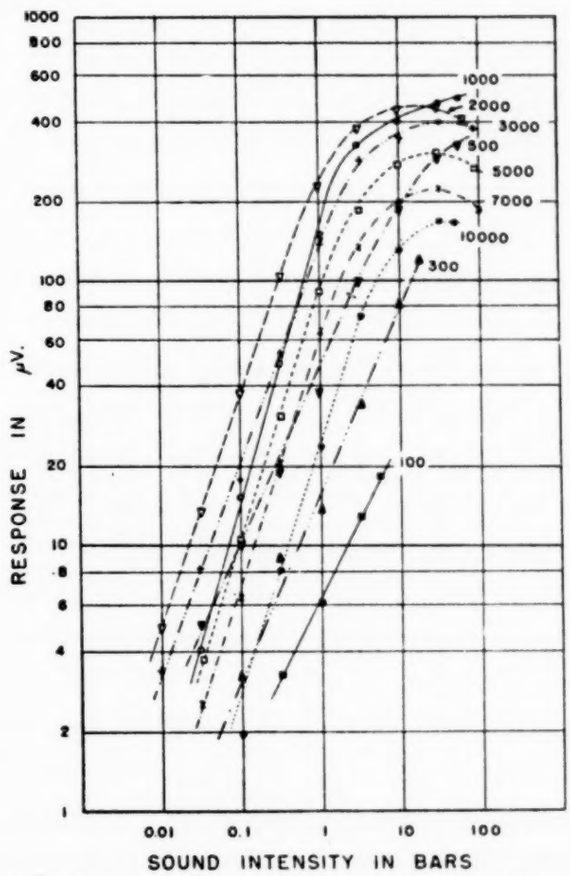


FIG. 4. Intensity functions for animal No. 7R. The numbers at the top of the curves indicate sound frequencies.

animal No. 4 is the most sensitive, and No. 3 is the least sensitive. For the most part, sensitivity is a general characteristic of an animal: if the animal is high in sensitivity for certain tones, it is likely to be so for others also. Thus the

curves for the four animals maintain much the same order in the three figures. However, variations are frequent, and differences in slope may change the order of sensitivity at different levels of response, as, for example, for animals No. 7 and No. 12 in Fig. 1.

A typical set of functions for various frequencies in a single animal is shown in Fig. 4. In this figure are given curves for 9 tones from 100 to 10,000~. Particularly to be noted in this figure are the differences in the maximum level of response for different frequencies. In general, the highest levels are reached with tones of the middle range. Variations of sensitivity with frequency are also evident.

Variations of sensitivity with frequency are more clearly shown by expressing the data in the form of equal-response curves. Data from another animal are shown in this form in Fig. 5. Each curve in this figure indicates the intensity of

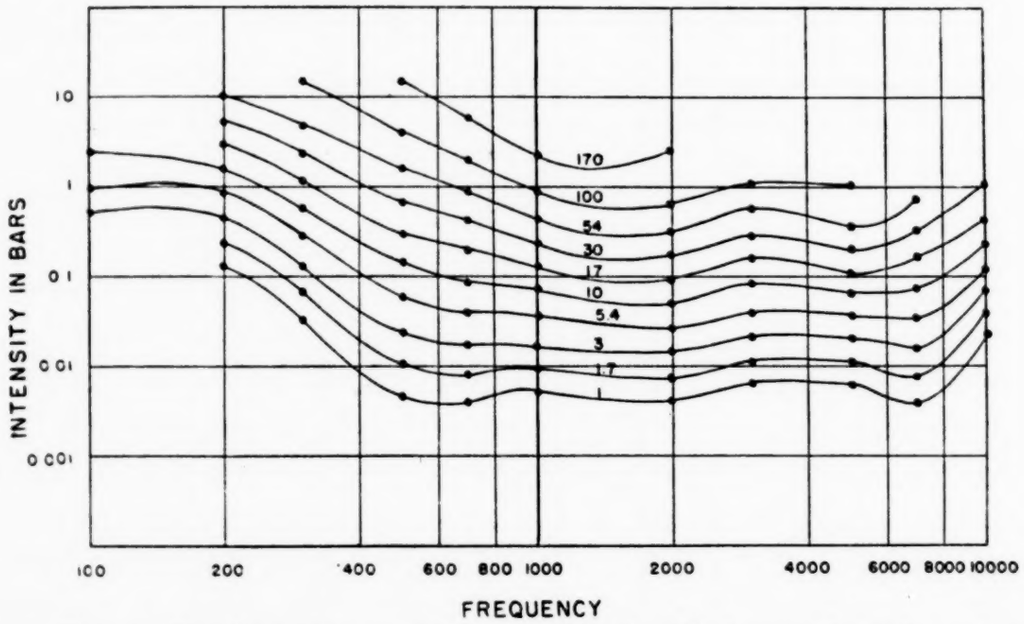


FIG. 5. Equal-response curves for animal No. 5L. Each curve shows, for various frequencies, the intensity of sound necessary to produce a given magnitude of response. The magnitude of response represented by a given curve is stated in μv. by the number above the curve.

sound necessary to produce a particular magnitude of response for various tones between 100 and 10,000~. The magnitude of response for which each curve is drawn is indicated, and values have been chosen at approximately equal logarithmic

steps from 1 to 170 μv. It will be observed that at low levels of response the sensitivity shown by this animal is fairly uniform between 500 and 7000~, and falls off rapidly for lower and higher frequencies. At higher levels of response the curves change their form somewhat, especially in the lower portion of the frequency range, so that tones below 1000~ require relatively large intensities for a given response. The changes in the form of the equal-response curves with changes of response level reflect the fact that curves for different frequencies have somewhat different slopes.

Individual animals differ in many details of their equal-response curves, but all the cats that we have tested exhibit the same general type of sensitivity: they are most sensitive in the middle range and considerably less sensitive for very high and especially for very low tones. The variations of sensitivity with frequency are characteristically different for cats and for guinea pigs.[7] These differences probably reflect anatomical and physiological peculiarities of the ears.

Variability of the Response.—An important feature in relation to the cochlear response is the degree of variability of observations. Special attention has been given to this matter in the present study, and an examination of Fig. 2 will show that for these functions two complete sets of observations were made. The degree of agreement between the various pairs of points is easily seen; in those instances in which but one point is shown the two observations were the same. The greatest variability, as measured on a logarithmic scale, is found at the lowest levels of response.

There are numerous causes of variability in these experiments. There are first of all the usual instrumental and observational errors. In addition, two types of variations are introduced by the animal. These are variations in the background of electrical effects from the tissues and variations in the actual sensitivity of the ear.

(1) Instrumental errors can be considered negligible so far as the general form of the intensity function for any given frequency is concerned. The instruments used in measure-

[7] Wever and Bray, *J. Exper. Psychol.*, 1936, **19**, 129–143.

ment and calibration can be read with a relative accuracy within 2 percent or less.

The absolute accuracy is close to the relative for all readings except those of sound intensity; we estimate that these readings are correct within an extreme limit of 10 db. It is difficult to deal with sounds over a wide range of frequencies with greater absolute precision.

(2) The lowest level of responses which can be observed accurately is determined by the background of electrical effects. Disturbances arise in the electrical system and in the physiological preparation itself, and the observation involves a discrimination between the response and these adventitious potentials. In our apparatus the amplifier noise has been reduced to a level below that of the physiological noise, and thus may largely be neglected.

Physiological disturbances arise from all tissues in the region of the electrodes. Insofar as they form a fairly steady base, they can readily be taken into account, and even sporadic effects can be made tolerable by taking observations in quiet intervals.

A more serious type of disturbance consists of potentials which apparently have their source in muscles and nerves excited reflexly by the sound stimulus. These potentials may be coincident with the cochlear response, and may add to the observed deflections. They are distributed over a wide range of frequencies, but are much more concentrated at the low-frequency end. Therefore the disturbance is greatest for low frequencies, and decreases progressively as the frequency is raised.

Since this type of disturbance operates largely in one direction, it cannot be averaged out through repetition of observations. It may be reduced, however, by deep anesthesia.

The most satisfactory method of dealing with the interfering effects that remain in deep anesthesia is to restrict the range of sensitivity of the apparatus. Since the potentials which arise from the extraneous activities are widely distributed over the frequency range, any restriction of range

reduces their effectiveness as a disturbance. Within any given region of frequency, the reduction is nearly in proportion to the restriction of range. However, this procedure does not overcome the inequalities in the distribution of these effects: the low-frequency end of the scale continues to show a relatively large amount of the disturbing potentials.

The wave analyzer used for some of the observations in the present experiments had a high selectivity. By its use the interference was reduced to the point where measurements of 0.1–0.2 μv. could be obtained with an accuracy greater than that possible for 1–2 μv. with the cathode-ray oscillograph. Measurements at these low levels are shown in the results for 1000~ in Fig. 2. This method is applicable only when the response to be measured is sinusoidal, or, if it is complex, where a satisfactory measurement need include only a limited number of components. The cochlear response at low levels is near enough to a sine wave for the application of this procedure. At high levels where the response is distorted the fundamental component of course differs from the complete wave in absolute value, but the intensity function which it yields does not differ greatly in form from that of the complete wave. These facts may be noted in comparing the curves for animal No. 12 in Figs. 1 and 3, which were obtained with the wave analyzer and represent the fundamental only, with the curves for the other three animals in these figures, which were obtained with the cathode-ray oscillograph. This point was proved by measuring the overtone components of the response and adding them to the fundamental; the resulting curve was raised about 20 percent above that of the fundamental at the maximum, but the general form was not much different.[8]

(3) The sensitivity of the ear of an animal is not fixed but is subject to change through the action of the muscles of the middle ear. It is now generally accepted that these muscles are protective in function; they contract reflexly to sound and in doing so they reduce the cochlear response.[9]

[8] Wever and Bray, Distortion in the ear as shown by the electrical responses of the cochlea, to appear in *J. Acoust. Soc. Amer.*

[9] C. S. Hallpike, On the function of the tympanic muscles, *J. Laryngol. and Otol.*, 1935, **50**, 362–369; Wever and Bray, *J. Exper. Psychol.*, 1936, **19**, 131; see also W.

The reflex contractions seem to be more frequent and more vigorous at the greater intensities of sound. The variations from this cause are therefore more likely to occur with observations at the higher levels. Variations of this type may be diminished by deep anesthesia or by operative exclusion of the middle-ear muscles.

Discussion

Intensity Functions.—The cochlear function for the cat has been found to have the same general form as that previously reported for the guinea pig: it is a power function up to the level at which overloading appears.

Cochlear functions for both cat and guinea pig have been considered by Davis and his collaborators. In successive reports they have described the functions in a great variety of ways, such as 'linear,' 'logarithmic,' 'neither linear nor logarithmic,' and 'roughly hyperbolic.' It should be made clear that though the descriptions varied the data included in the reports were much the same as those obtained by ourselves, so far as comparison is possible.[10]

In the most recent discussions by Stevens and Davis, the cochlear function (for the guinea pig) is said to deviate from "the Weber-Fechner relationship in the same manner as do the psychological [loudness] functions," and "as a first approximation, the form of the loudness function is imposed by the behavior of the cochlear mechanism." A reservation made to the latter statement is that "the cochlear function is slightly sigmoid in form." [11]

The human loudness function that was used in the above comparison was derived by Churcher on the basis of various observations.[12] The curve on double-logarithmic coördinates may be drawn with a slight but fairly regular concavity downward, or it may be drawn as a series of two or three straight

Hughson and S. J. Crowe, Experimental investigation of the physiology of the ear, *Acta oto-laryngol.*, 1933, **18**, 291–339.

[10] See the discussion in *J. Exper. Psychol.*, 1936, **19**, 140*f.*

[11] S. S. Stevens, and H. Davis, Physiological acoustics: loudness, *J. Acoust. Soc. Amer.*, 1936, **7**, 238; Psychophysiological acoustics: pitch and loudness, *op. cit.*, 1936, **8**, 5–7.

[12] B. G. Churcher, A loudness scale for industrial noise measurements, *J. Acoust. Soc. Amer.*, 1935, **6**, 216–226.

lines. Churcher considered the true function as complex, but regarded it as roughly expressed by an equation in which loudness is proportional to the logarithm of sound intensity (in absolute units). At any rate, the function is not a simple power function, though separate segments may be satisfactorily fitted by power functions.

When we draw Churcher's curve on the same graph with our cochlear functions for cat and guinea pig, the correspondence is not very striking. The curves of cochlear response have considerably greater slope. The guinea pig curve illustrated by Stevens and Davis with a slope similar to that of Churcher's curve is not typical according to our observations.

On theoretical grounds we should expect a relation between the cochlear response of an animal and loudness as experienced by that animal, inasmuch as there is reason to believe that the cochlear response represents the action of the sense organ.[13] However, since nervous processes follow the cochlear response it should give no surprise if when a way is found to study loudness in an animal its function fails to correspond closely to the cochlear function. Certainly a comparison of cochlear functions in cats and guinea pigs with loudness functions in man does not convince us of a direct relation. Therefore we maintain our former position that the Weber relationship between sound intensity and loudness must be sought in processes beyond the receptor.

We do not regard the 'slightly sigmoid' manifestation of Stevens and Davis' results as a typical feature of the cochlear response. (Here we refer to the upward tendency at low stimulus intensities; not to the downward bending of the curves at high intensities, about which there is no question.) That upward displacements of the curves at low intensities do sometimes occur is not disputed: the problem is simply whether this condition is general, and what is its cause. We have occasionally observed such displacements for both cats

[13] H. A. Howe and S. R. Guild, Absence of the organ of Corti and its possible relation to electric auditory nerve responses, *Anat. Rec.*, 1933, **55**, Suppl., 20–21; H. A. Howe, The relation of the organ of Corti to audio-electric phenomena in deaf albino cats, *Amer. J. Physiol.*, 1935, **111**, 187–191.

and guinea pigs. As Stevens and Davis correctly have pointed out, an instance for the guinea pig may be seen in some of our published results.[14] These authors imply that the displacement is absent in our other curves because the observations did not extend to sufficiently low intensities.

In our treatment of the guinea pig results, the view which we held regarding these displacements was that on occasion external potentials reflexly or otherwise excited in neighboring nerve and muscle tissues add to the true cochlear response. There are several reasons for this view. (1) The displacements do not regularly occur. (2) When observations are repeated, more often than not a 'sigmoid tendency' fails to reappear. (3) The variations are much more common for low than for high frequencies. (4) They are reduced as anesthesia is made deeper.

In the present experiments we have made a special effort to clear up this question. By suitably deep anesthesia we have reduced the adventitious effects, and by the use of selective amplification, as afforded by the wave analyzer, we have reduced the background considerably below the ordinary level. By these means we have been able with reasonable accuracy to make measurements of potentials 20 db. below those formerly possible. Figure 2 shows these measurements for 1000~. The curves continue as a power function through the region of 10 to 1 μv. that under other conditions, with the cathode-ray oscillograph, occasionally shows the 'sigmoid tendency,' and then the same function continues downward to at least 0.2 μv. Below 1 μv. a moderate degree of variability is shown, but there is no indication of sigmoid form. Thus the cochlear function is a power function from the lowest levels at which measurements are possible by methods so far developed up to the region of bending at high intensities.

'*Thresholds.*'—The above observations apply to a further question raised by certain statements of Davis and his associates regarding what are termed 'thresholds' for the cochlear response. We have already pointed out, in dealing with the cochlear response in the guinea pig, that no absolute

[14] *J. Exper. Psychol.*, 1936, **19**, 132 *ff.*

thresholds appear within the limits of sensitivity of our apparatus. The same remains true for the cat, even when the sensitivity has been increased more than tenfold.

The 'thresholds' that have been reported by these writers are expressions of the limitations of recording apparatus. At times they have made this fact clear by saying that the 'thresholds' represent the least perceptible deflection on the cathode-ray oscillograph.[15] At other times, however, they appear to have lost sight of this limitation, for they have made use of the observations as though they represented actual thresholds. Thus at several different times they have stated that the 'threshold' of the cochlear response for different frequencies "corresponds closely to the human audibility curve." [16] The comparison is made both 'qualitatively and quantitatively.' [17]

If observation of the cochlear response is limited by the recording apparatus, then it is plain that no quantitative comparison of human and animal results is possible. A rough comparison of the forms of the curves might be justifiable, even though the level for one was at threshold and that of the other some unknown distance above threshold, or simply at an arbitrary level, if the conditions of observation were such as to give results that were equally valid for different frequencies. But this last assumption cannot be made. As mentioned earlier in this article, the energy contained in stray electrical effects is not spread uniformly over the frequency spectrum, but is relatively concentrated at the low-frequency end. Therefore, minimum deflections for high and low tones are not observed under equally favorable conditions.

There is no serious objection to the use of these minimum perceptible deflections in comparisons between individual animals, or comparisons of cochlear and nervous responses, or in other situations where the peculiarities of the recording

[15] *E.g.*, A. J. Derbyshire and H. Davis, The action potentials of the auditory nerve, *Amer. J. Physiol.*, 1935, **113**, 482.

[16] H. Davis, A. J. Derbyshire, M. H. Lurie, and L. J. Saul, The electric response of the cochlea, *Amer. J. Physiol.*, 1934, **107**, 322.

[17] H. Davis, The electrical phenomena of the cochlea and the auditory nerve, *J. Acoust. Soc. Amer.*, 1935, **6**, 211.

system and the background may reasonably be assumed to affect both sets of results in a similar manner. However, even in these situations it is obviously preferable to work at levels high enough for reliable quantitative measurements.

We have used observations at levels of minimum perceptibility only to explore the extreme limits of frequencies at which the responses occur, and have accepted the results of such observations merely as a crude comparative measure that reflects the limitations of our apparatus and conditions.

Equal-response Contours.—The 'threshold' fallacy is further involved in the comparison that Stevens and Davis have made between equal-loudness contours in man and equal-response contours in the guinea pig.[18] For this comparison they drew on the same graph the 45 db. equal-loudness contour as presented by Fletcher and Munson [19] and the contour of equal-cochlear response for guinea pigs at 45 db. above 'threshold.' These two curves they regarded as significantly alike, especially since they explained differences at low frequencies as due to 'interference' with the cochlear responses by nerve impulses. On the basis of the similarities that they saw, they concluded that "it is the behavior of the receptor mechanism which imposes the form which we find in equal loudness contours."

We do not consider that this conclusion can properly be derived from the presented data, or from any data now available. Our position rests upon the following considerations:

(1) The agreement which Stevens and Davis have found between the contours is not outstanding, and their explanation of the divergences at low frequencies is hardly acceptable. To 'interfere' in the required manner the nerve impulses must be present in considerable magnitudes, and must be so related in phase as to contribute to the total response at some frequencies and detract from it at others. There is no evidence in their results, or in any that we have obtained, that these conditions are met.

[18] S. S. Stevens and H. Davis, Psychophysiological acoustics: pitch and loudness, *J. Acoust. Soc. Amer.*, 1936, **8**, 4 *ff*.

[19] H. Fletcher and W. A. Munson, Loudness, its definition, measurement and calculation, *J. Acoust. Soc. Amer.*, 1933, **5**, 82–108.

(2) Since the reference level for the contour of the guinea pig is based upon 'thresholds,' *i.e.*, indeterminate conditions of observation, that level itself is necessarily indeterminate. And since the contours of an animal undergo changes of form with response level, it would only be by accident that the proper contour was chosen for the comparison.

(3) Contours of equal cochlear response vary among animal species. Those for pigeons, opossums, guinea pigs, and cats show characteristic differences.[20] There is no apparent reason for preferring the guinea pig to the cat for a comparison with man. Hence any resemblance that Stevens and Davis have found with one of these animals can hardly lead to their conclusion that human loudness contours directly represent the behavior of the receptor.

(4) There is little question that the contours of cochlear response reflect properties of the end-organ. But the loudness functions do not do so in a direct manner. They reflect the combined characteristics of end-organ, nerve tracts, and perceptual systems. An analysis of these characteristics may be possible, but, it would seem, not on the basis of such a comparison as here discussed. What is further needed for a meaningful comparison is a study of loudness functions in animals, or of cochlear functions in man.

A valuable study of cochlear responses in the cat has been made by Covell and Black.[21] Their results on the form of the intensity functions and the variation of sensitivity with frequency are in good agreement with those reported in the present paper. They deny, as we do, that equal-response levels are to be identified with equal-loudness levels, and point out that equal-response curves do not undergo the same changes of form with change of response level as do equal-loudness curves in man with change of loudness level.

Summary

Results are presented for the cat to show the functional relationship between sound intensity and the magnitude of

[20] Wever and Bray, A comparative study of hearing in vertebrates, *Psychol. Bull.*, 1936, **33**, 607; A comparative study of the electrical responses of the ear, to appear in *Proc. Amer. Philos. Soc.*, 1937.

[21] *Amer. J. Physiol.*, 1936, **116**, 524–530.

responses in the cochlea. This relationship is found to be a power function for all except the highest intensities of stimulation. Previous indications in a few curves of a 'sigmoid tendency' at low levels are accounted for by the presence of adventitious potentials. At high levels, the curves depart from a power function in such a way as to suggest a serious overloading of the ear.

An analysis is made of the conditions of observation of cochlear responses, and the causes of variability. Variations may be traced to three sources, which are the instruments of measurement, the presence of adventitious potentials, and changes in the sensitivity of the ear through action of the tympanic muscles.

The results for the cat show characteristic differences of detail from those for other animals, due to differences of anatomy and physiological activity. The similarities are striking, however, and confirm the general principles previously derived. No absolute threshold has been discovered for the cochlear response, and there is no reason to suppose that any exists. The origin of the Weber relationship between stimulus intensity and loudness must be sought in processes central to the receptor. The character of the functional relationship between loudness and frequency also is probably dependent upon central processes, though it doubtless reflects in an indirect manner the properties of the end-organ.

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OCULAR PURSUIT IN NORMAL AND PSYCHOPATHOLOGICAL SUBJECTS

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I. Introduction

The eye movements which occur when an *S* is visually pursuing a small bright object oscillating harmonically in a lateral path before him have been identified with the slow phase of optokinetic nystagmus (**18**). That is, they resemble the type of eye movements which would occur when an individual with head held stationary watches an automobile pass laterally before him, in contrast to the saccadic eye movements which would occur in reading. A rather large number of characteristics of pursuit movement have been described for normal *S*s and for *S*s with certain organic pathologies. Some of the conditions which have been shown to modify ocular pursuit in experimental studies are as follows: clarity of vision—neither foveal nor clear vision seems to be necessary for pursuit to occur (**6**, **7**, **9**, **11**, **13**, **15**, **27**); nature of the stimulus—stimuli which evoke especial interest are pursued longer (**3**, **10**, **21**, **27**); velocity of the stimulus—apparently there is a maximal velocity of the stimulus object, and also, above or below an optimal velocity pursuit is less likely to occur (**12**, **27**); size of the visual field—there is a tendency for optokinetic nystagmus to increase with the increase of width of the visual field through which the stimulus passes, with foveal vision seemingly more effective than peripheral (**11**, **24**, **27**); fixation—the presence of a fixation point within the field lessens the probability that pursuit will occur, the effectiveness of such a point being in part determined by its size (**9**, **24**); direction of pursuit—the pursuit seems to be slightly better when the stimulus moves nasalward, but the

A condensation of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

findings do not seem to be conclusive (**3, 10, 27, 28**); cessation of stimulus—ocular pursuit may persist after the stimulus object has been removed (**6, 10, 23**); level of attention—very little attention seems to be necessary for the production of pursuit, yet in general those situations which lower attention lessen the adequacy of pursuit (**3, 21, 26**).

These studies early were extended to psychopathological case material by Diefendorf and Dodge (**5**), who reported that the eye movements of dementia præcox, dementia paralytica, and manic patients were faster than eye movements of normal individuals, while the movements of depressed patients were slower. In the records of pursuit elicited by a harmonically oscillating object they found that dementia præcox and dementia paralytica groups show eye movements which are 'characteristically step-like,' rather than approximating simple sine waves. Hysterically blind patients were found by Ohm (**25**) to abandon pursuit relatively early. In a recent study Couch and Fox (**4**) reported that the 'step-like' pursuit described by Diefendorf and Dodge was not confined to dementia præcox and paralytica groups, and furthermore, found the pursuit response to be entirely normal in 16 patients. In 60 cases they found only disorders of 'attention' and in 41 more, 'evidence of defect or inadequate adjustment.' A striking feature of their records was the variability of response, in different patients within the same diagnostic group and in the same patient under different experimental conditions. Occasionally a normal response was obtained from a very 'sick' individual. Sudden hallucinatory experiences in themselves did not cause any deviation in the record line. 'Negativism' was clearly demonstrated in the records of three patients who were in a catatonic stupor.

In all studies such as those above wide individual differences among the *Ss* or patients used have made the results more difficult to interpret. There seems to be considerable variation in the amplitude and latency of pursuit movement (**10**), even among normal individuals (**27**); attention has also been called to variations in frequency and regularity of ocular movements in optokinetic nystagmus (**22**). Associated re-

actions, such as the tendency of *S* to move in the direction of the stimulus, are encountered in examining eye movement records (**11, 30**). In general these writers have warned against building general diagnostic syndromes from small differences between eye movements.

It is the purpose of the present study to carry further the comparison of normal with psychopathological *Ss*. Insofar as possible the cautions of previous workers in the field have been heeded in the attempt to eliminate distorting experimental factors from the results.

II. Subjects

Records were secured from 20 normal *Ss*, and 38 patients of the psychopathic hospital in Iowa City. Among the latter there were 17 cases diagnosed as schizophrenic, 8 as manic-depressive, and 13 as psychoneurotic. In the normal group three records were taken at weekly intervals. The patients were examined at various intervals in the attempt to determine the alterations in ocular movement concomitant with alterations in their general behavior.

III. Apparatus

Recording Technique.—Each record consisted of a photographic recording of the eye movements elicited by approximately 10 oscillations of the pursuit object, at each of five velocities. The responses were photographed by means of a modification of the Dodge mirror-recorder (**7, 29**). During all recording the left eye saw the object and records were taken from the right eye. The distance from the mirror-recorder to the camera was 60 cm.

A signal circuit closed by a commutator mounted on the shaft driving the pendulum identified the interval from the moment immediately before the stimulus reached the extreme temporal deflection until immediately after it had started to return nasalward. A second signal circuit, closed by a commutator mounted on a shaft driven directly by the synchronous motor, was used in recording a time line in .1 sec units.

During the recording the room was illuminated by a photographic ruby lamp, the stimulus light, the recording light and the signal lights. The total general illumination was but little more than that of the usual photographic dark room. The use of a biting board reduced the amount of head movement by *S*, further control being added by supports fitting against the back of the head. Movements of the lid of the (recording) right eye were partially eliminated by the use of an adhesive tape lid-holder.

Stimulus for Pursuit.—The object of pursuit was the light of a flashlight bulb behind a small diaphragm with a pin-hole opening, mounted on an inverted pendulum 60 cm long. The pendulum was driven in harmonic motion by a synchronous motor through a pulley system. This system was designed to permit a period of oscillation 3.6, 1.5, .9, .6, or .4 sec in length (and since the average velocities varied inversely with the period, they will be referred to as velocities no. 1, 2, 3, 4, and 5, respectively). The amplitude of the oscillation was fixed at 12 cm. *S* viewed the light stimulus through a dark tube, 75 × 14 × 16 cm, the latter dimension being the width. The stimulus passed through approximately 9° of the visual field.

Phenomenological Field.—When stationary, the stimulus appeared as a small spot of bright light, with, for most *S*s, astigmatic lines. The *S*s were instructed before the oscillation at each speed began, "You are to watch the light carefully and follow it with your eyes as it moves back and forth across the tube."

When oscillating at lower frequencies the stimulus was perceived as a distinct spot passing back and forth along a slightly arched route. When the period of oscillation was 3.6 secs (velocity no. 1) the report usually was that the stimulus was moving too slowly to be followed easily. With increasing velocities of the stimulus, its path was no longer perceived as arched. Whenever the period of oscillation was less than 1.5 secs (velocities 3, 4, or 5) the *S*s reported that the light travelled a shorter distance. At still greater angular velocities it was described as being trailed by a 'tail' of light. Several *S*s reported that the stimulus described a flat horizontal ellipse or figure-of-eight, the far side being slightly higher. With still greater velocities, the 'tail' extended across the entire path. The stimulus might be seen as a spot, first at one end of the path and then at the other, or as a spot of light moving across a line of light, or it might lose its identity in the line of light. The angular velocity of the stimulus at the time of the alteration in its perceived character varied from *S* to *S*. With the exception of the perceived shortening and flattening of the path of the stimulus the alterations were not characteristic of the two lower velocities used.

IV. Ocular Pursuit in Normal Individuals

Characteristics of Normal Pursuit

The visual pursuit of a moving object showed an average latency of approximately .19 sec. The first eye movement subsequent to the beginning of stimulus movement was usually either a quick refixation or a slow drift. Then by saccadic movement the eyes 'caught up' with the stimulus object and from then on maintained the approximately correct velocity. However, even the full sweeps of pursuit were not completely smooth curves, but were broken by quick movements, usually in the direction of pursuit. In following the pendulum, the eyes of *S* described, with these irregularities, harmonic movements with periods determined by the period of the oscillating stimulus.

Deviations from the Pure Pursuit Pattern

Variations in Amplitude of Movement.—1. The successive phases of like-directed (*e.g.*, temporalward) eye movements may differ in amplitude. This was true for both the total amplitude of the eye movement (saccadic and pursuit movements combined) and for the extent of pure pursuit movement.

2. When the average amplitudes of the pure pursuit

movement for the nasal and temporal directions for a series of records were computed, it was seen that there was a tendency for a greater amount of pursuit to occur when the stimulus moved nasalward (see Table I). This was borne

TABLE I

RELATION OF AMOUNT OF EYE MOVEMENT TO DIRECTION OF PURSUIT

Velocity*	Number of Cases With Amplitude Greater		Ampl. Equal	Number of Cases With Pure Pursuit Greater		Pur. Equal
	Nasal Direction	Temporal Direction		Nasal Direction	Temporal Direction	
1	12	13	0	18	7	0
2	10	13	2	21	4	0
3	10	14	0	22	2	0
4	10	8	1	14	5	0
5	1	2	0	2	1	0
Totals	43	50	3	77	19	0

* In this and following tables the velocities are in inverse proportion to the period of the pendulum, so that velocity 1 is the slowest used and velocity 5 the fastest.

out when the records from 8 individual *S*s were analyzed, for it was found that in only one *S* of this group was the pursuit consistently longer in the temporal direction.

This directional advantage did not hold for average total amplitude of eye movement. Apparently the greater pursuit in the nasal direction was counteracted by greater saccadic movement in the temporal direction.

3. It may be seen in Table II that at only the two lowest

TABLE II

RELATION OF AMOUNT OF EYE MOVEMENT TO VELOCITY OF PURSUIT STIMULUS

Velocity	Number of Cases Showing Greatest Excursion at Each Period of Oscillation	
	Total Amplitude of Eye Movement	Pure Pursuit
1	26	43
2	25	16
3	6	0
4	2	0
5	0	0
Totals	59	59

velocities were pure pursuit movements of greatest excursion. Apparently as the pendulum is speeded up, it becomes impossible for the eye to make the full sweep necessary to follow

through the arc, and still maintain the pursuit type of movement, throughout a series of oscillations.

The numbers of individuals having greatest total amplitude of eye movements are equal at the two lowest velocities. That is, when saccadic movements are included with pursuit, it seems to be possible for each *S* to follow the stimulus object through its complete arc. However, as the velocities increase, the number of *S*s showing greatest total amplitude decreases, with none showing greatest amplitude at the highest velocity. This suggests again that an upper 'threshold' of capability has been reached. In one record from each of two *S*s the total amplitude reached a maximal extent when the stimulus moved most slowly, and the pure pursuit did not reach its maximal extent until the no. 2 velocity was reached. In all other cases, total amplitude and pursuit reached maximal extents at the same velocity, or pure pursuit reached a maximum at a lower velocity than did amplitude. In general it may be said that increasing velocity makes it more difficult to visually follow the stimulus object to the full extreme of its movement.

4. During the course of several consecutive oscillations there may be a gradual diminution in the extent of the eye movement, followed immediately by a gradual increase in the extent of eye movement back to the original value. This response was very infrequent, even in the mentally diseased individuals who will be discussed later.

Variations in Temporal Relationships.—1. The most stable characteristic of the ocular response was the regular periodicity of eye movement in relation to oscillations of the stimulus.

2. The duration and frequency of the saccadic movements tended first to increase and later to decrease with increasing velocity of the objective stimulus. This was in accord with the finding of Dodge, Travis, and Fox (**10**).

3. The concept of pursuit implies a definite relationship between velocity of stimulus and rapidity of eye movement. The extent of the arc of the stimulus divided by its period should vary concomitantly with the extent of the eye movement divided by its period. Such was not the case in the

records obtained (see Table III). As the duration of the period shortened the extent of the arc of the stimulus divided by its period increased. However, the extent of the eye movement divided by its period increased, passed through

TABLE III

RELATION OF EXTENT OF EYE MOVEMENT DIVIDED BY DURATION TO THE DURATION OF THE PERIODS OF OSCILLATION

Velocity	Maximal Value, Amplitude/Duration	Maximal Value, Pursuit/Duration
1	0	0
2	13	21
3	36	33
4	10	5
5	1	1

a maximal value, and then decreased. The same relationship prevailed if the extent of pure pursuit was divided by its duration.

4. Several records deviated from adequate pursuit in that they showed a consistent lag of the eye line with regard to the position of the stimulus as indicated by the signal lamp.

Variations in Direction.—1. When the movement of the eye lagged behind the movement of the light, the stimulus and the eye moved in opposite directions at the extremes of the deflection.

2. Infrequently the eye line was observed to travel in a direction opposed to the motion of the stimulus, although the velocity of the eye line corresponded to that expected for a pursuit movement. This reaction seems analogous to the 'negativism' reported by Fox and Couch (4). It was found for short extents under the present experimental conditions, even in normal records.

Associated Movements

Pursuit behavior is not confined to the ocular response. A few records show head movements of small amplitude, some having the same period of oscillation as the stimulus object. When they are of small amplitude the head movements appear to be independent of the eye movements, the head line tending to arrive at the extreme deflection earlier than the stimulus. In two records obtained from patients, the amplitude of the

head movement was as great as the average amplitude of the eye movement. In these records the head and eye lines are parallel.

V. Ocular Pursuit in Mentally Diseased Individuals

When possible, the records from the patients were analyzed quantitatively in terms of the total amplitude of eye movement, and the amplitude of pursuit movement, in the same manner as for the normal group. When pursuit was present it was of the same amplitude as in the normal Ss, and showed the same tendency to decrease in amplitude as the velocity of the pursued object increased.

Psychoneurotic.—The records of the psychoneurotic group rather closely resembled those of the normal group throughout. The amplitude of successive phases of eye movement was more variable, and the frequency and extent of the saccadic movement was greater than in the normal group. This became more distinct as the velocity of the object of pursuit increased. While pursuit was consistently present at lower speeds, only three of the 13 Ss maintained pursuit when the light made an oscillation at the no. 4 velocity. The Ss were consistent in the general pattern of optic pursuit shown at successive recordings.

Schizophrenic.—In the records of the schizophrenic patients showing marked behavior disturbances there was an accentuation of the same irregularities as in the psychoneurotic group. There was a slight tendency for the pursuit to be less variable and to more closely resemble that found in the normal group as the general pattern of behavior approached normalcy. Records taken while the patients were experiencing visual hallucinations showed well sustained but irregular patterns of pursuit. An attempt was made to determine the effects of sodium amytal on the ocular adjustments of several of the patients showing more marked behavior disturbances. During the effective period of the drug there were marked alterations in the general behavior of the patient. In some cases this was accompanied by changes in the ocular

adjustment, but there was no consistency in the relationship, even for the same *S* at successive recordings.

Manic-depressive.—The records of the manic-depressive group showed a closer correspondence between the alterations in pursuit and the alterations in the general pattern of behavior. In six cases there was evidence of this adjustment in ocular pattern concomitant with alteration in general behavior. But two cases with the least severe degree of disorder did not show this alteration.

VI. Summary

Normal Individuals.—1. Successive phases of like-directed movement may differ in amplitude.

2. For our *S*s there is a tendency for greater pursuit to occur when the stimulus is moving nasalward for the seeing eye, although the total amplitude of the eye movement tends to be approximately equal in both directions.

3. As the velocity of the stimulus increases, within the limits used in this experiment, the amount of eye movement decreases. An exception is found perhaps in the two lowest velocities used, where the speed of the stimulus object is sufficiently slow that complete pursuit is possible.

4. The duration of eye oscillations corresponds to the duration of stimulus oscillations.

5. The duration and frequency of saccadic movements tends first to increase and later to decrease with increasing velocity of the stimulus.

6. The ratio of extent of pursuit or total amplitude of eye movement to the period of the stimulus oscillation does not increase continuously with the corresponding function of the stimulus but passes through a maximum value and decreases.

7. The eye may lag behind the pursued object.

8. Pursuit behavior is not confined to the ocular response. Head movements may be independent of eye movements to some extent, arriving somewhat sooner at the extreme of deflection than the stimulus for pursuit.

Mentally Diseased Individuals.—There was no pattern of ocular adjustment in the patients that was not found also in

the non-patient group. Neither 'negativism' nor 'step-like' pursuit was found to have any diagnostic significance. In records of both the normal and psychopathic Ss the amplitude of eye movement and pursuit movement was approximately identical, and decreased with increasing velocities of the pursued object. In both sets of records the duration of oscillation of the eye corresponded to the duration of oscillation of the pursued object. This relation was constant at all frequencies of oscillation. The difference between mentally diseased and normal individuals lay in the greater irregularity and earlier abandonment of pursuit in the former. The mentally diseased individuals showed, in greatly exaggerated form, certain characteristics of optic pursuit which were found in normal individuals.

VII. Discussion

There at present are at least five interpretations of the pursuit process. Bühler (**2**) states his conception as follows: "When carefully examined, these processes reveal a complicated and finely differentiated system of interconnections between the impression of the light upon separate points of the retina and the specialized impulses of eye movements. Strictly speaking, a different movement must arise from every retinal point: therefore every fiber of the optic nerve must have a different central connection with the motor nerves which innervate eye movements." Koffka (**16**, **17**) objects to the theory in part because of the enormous number of connections which necessarily would have to be arranged in a definite manner so as to produce the orderly results of fixation. The experiments of Marina (**19**), who first interchanged the medial and lateral recti muscles, and later substituted the superior rectus for the lateral rectus muscle, definitely disproved such a theory since he found that the conduction pathways have no pre-determined function.

A second hypothesis is that pursuit may be regarded as a kind of conditioned response in which a given velocity of stimulus may evoke a very different velocity of eye movement (Dodge, **8**). He suggests, as a criticism of this view, that it would involve an extremely complex reaction system and

that the pursuit pattern becomes fully developed more rapidly than would be expected on the basis of conditioning. He suggests that there is a further difficulty since the conditioned eye movement evoked by any particular speed of the object would depend on whether the object of pursuit was in a phase of acceleration or of deceleration. Additional emphasis is given to these objections when Table III of the present report is considered. If the conditioning theory and the implied relationship between stimulus and response is correct, the extent of eye movement divided by its period should reach a maximum when the period is shortest, since the arc of the stimulus is constant. This was found to be true only in the case of one *S*, in one record. In over half the cases this function reached a maximum at the third velocity.

Probably the most generally accepted concept of the nature of the pursuit movement is the third hypothesis, that it is due to the impulse 'to hold the image of the object motionless on a retinal area of relatively clear vision' (Dodge, Travis, and Fox, **10**). When the alterations occurring in the pursuit pattern with increasing velocities of the stimulus are considered, this theory seems untenable. The difference between the amplitudes of successive phases of eye movements in the same direction prevents retention of the image of the stimulus upon a restricted area. Any lack of equality between temporal and nasal pursuits has the same effect. Although the arc of the stimulus is constant, the extent of the eye movement decreases with increasing velocity of the stimulus. Therefore the image of the stimulus must move along the retina.

In a fourth hypothesis, Dodge (**8**) has suggested that

> The objective motion is apprehended as a unitary configuration of accelerations to which the eye reacts with a unitary configuration of responses. . . . The sensory conditions for that integration would seem to be given in the character of the stimulus situation as apprehended during the first half-oscillation. At any rate the difference between the first and successive phases of pursuit forced us to regard the latter as the product of a learning process.
>
> Further evidence in support of this hypothesis is furnished by the regularity of some of the less adequate pursuit patterns and especially by the character of the post-excitation pattern after the sudden cessation of objective motion.
>
> That the integration of response is only partially adequate, however, is indicated by the small corrective movements that occur in even the smoothest pursuit. These are of various amplitudes, sometimes positive and sometimes negative in direction.

They are best understood as specific reactions to lapsed fixation. Moreover, pursuit may falter at eye-movement speeds well below that of saccadic corrections, and be followed by occasional moments of adequate pursuit. These facts would seem inconsistent with the closed integration of behavior patterns.

It is difficult to evaluate this hypothesis, but there seems to be some inconsistency in regarding pursuit movement as a response to a 'unitary configuration of accelerations,' but saccadic movement as a 'specific reaction to lapsed fixation.' Again Dodge speaks of the second and successive phases of pursuit as 'the product of a learning process,' yet in discussing the irregularities in ocular movement he states, "These facts would seem inconsistent with the closed integration of behavior patterns." If by a 'unitary configuration of accelerations' Dodge means that *S* perceives the stimulus as oscillating harmonically and that the unitary configuration of responses corresponds to this pattern, it is difficult to account for variability in the total extent of eye movement and in the pure pursuit movement. Saccadic movement, movement characterized by a velocity not given in the unitary configuration, cannot be accounted for, nor can the 'negativism' reported by Fox and Couch, and the similar eye movement found in the records of the present study. The treatment of saccadic movement as correcting lapsed fixation has been criticized above, since records fail to substantiate the hypothesis that the pursuit movement acts to hold the image of the pursued object motionless on the retina. However, if by the statement that "these facts seem inconsistent with the closed integration of behavior patterns," Dodge means to imply that he does not regard ocular pursuit as the product of a learning process or a "kind of short-lived habit which develops in each instance of pursuit" (Travis and Dodge, **28**) it is believed that the present report is in agreement with him.

Koffka (**17**) states that the eye movements take place in such a manner that the "organization resulting from the stimulation of the receptor is as good as possible." The eye movements are a result of a stimulus inhomogeneity and it is their function to bring the momentarily outstanding figure into the center of the field. ". . . We understand the whole

process as a process of articulation and balancing of the visual field." It is further assumed that "the perceptual field, by starting and steering it, influences the oculomotor system." In the present study, several characteristics of the eye movement seem to justify Koffka's assumption in the case of optic pursuit. There is an initial latency of approximately .19 sec before any eye movement occurs. The pursuit reaction is not established for an even longer time. Further support for Koffka's view is found in the study of Fischer and Kornmüller (**11**) who presented a small central field for optokinetic nystagmus, in which the bars were surrounded by a large peripheral field, similar in character but with the bars moving in the opposite direction. In this case alteration in the relative areas of the two fields is sufficient to determine the direction of the nystagmus, so the response must be made to a pattern. It has been shown by Irvine and Ludvigh (**14**) that the proprioceptive sense in extra-ocular muscles probably is lacking, or at least plays no rôle in the interpretation of motion on the retina. This is additional evidence against any point-for-point theory of ocular adjustment to a moving stimulus and suggests that motor control of this adjustment probably is a more generalized process.

The type of eye movements here found seems to be understandable on a pattern-response basis. At lower velocities of the stimulus, *S*s perceived 'a spot of light moving back and forth.' Under such conditions the image of the pursued object should be held approximately upon the foveal area (in the non-pathological eye) since it is in this region that the tendency for the formation of figure is the strongest. The saccadic movements are not to be understood as corrections of lapsed fixation, but rather as the resultants of competing stimuli.

In the present experimental series it is not possible to state definitely the cause of the individual saccadic movements. Among the possibilities which may be suggested are: attention to the dark tube through which the light was seen, incidental sounds, or central processes. As the angular velocity of the pursued object is increased the perceived field is reported as

being shortened; at the same time both the total amplitude of eye movement and the amplitude of the pure pursuit movement decrease.

At higher velocities of the stimulus light *Ss* describe the field as appearing: (1) as a spot of light with a tail; (2) a line of light along which a spot moves; (3) a line of light with a spot appearing first at one end and then at the other; (4) as a line of light. The first two phenomena suggest a possible explanation of the decrease in the values obtained by dividing total extent of eye movement and pure pursuit movement by the period of the stimulus. In these cases the size of the stimulus would be somewhat greater, which should cause the apparent velocity to be somewhat smaller than the true velocity, as shown by Brown's (1) studies of perception of velocity. The finding of Nordmann and Lieou (21) that there are frequent cases in which narrow bands fail to elicit pursuit while broader bands did produce it is understandable upon this same basis. The phenomena listed as 3 and 4 above are in correspondence with the fact that at higher velocities the eye line may show little or no pursuit movement, with a saccadic movement appearing at or near the end of a phase of eye movement in the direction of the stimulus light. It also is to be noted that in the absence of pursuit the eye does not return to a central position.

It may be concluded that the eye movements measured under the present experimental conditions are more adequately described in terms of *S*'s response to the whole perceived field than they are in terms of any more atomistic conception of the stimulus-response situation. The data of the present study support the theoretical considerations of Koffka, as contrasted with those of Bühler and of Dodge.

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THE COMPUTATION OF PSYCHOLOGICAL VALUES FROM JUDGMENTS IN ABSOLUTE CATEGORIES

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When stimuli are judged by the method of equal appearing intervals or by rating scale methods, we are frequently in doubt as to whether the observer is able to maintain the assumed equality of units with which the experimenter hopes the scale is endowed. We do not know whether or not there may be a systematic shift in the size of the unit from the lower part of the scale to the upper part, or whether there are irregular inequalities, though we often suspect that such distortions have occurred. It is the intent of this paper to attempt to derive new rational methods for computing scale values from data derived by these methods and to compare such values with those more directly computed from medians. The illustrative data were obtained by the method of equal appearing intervals and most of the remarks will be directed to this method in particular, but they also apply to rating-scale data, to data from the method of single stimuli, in fact to any data in which the observer or observers have placed stimuli repeatedly in two or more distinct categories, whether those categories are psychologically equidistant or not.

The Data Treated as Comparative Judgments

Suppose that a series of stimuli, R_a, R_b, R_c . . . R_n, have been judged repeatedly by placing them in psychological categories S_o, S_p, S_q, . . . S_z. Let

f_{au} = the number of times that R_a is placed in category S_u,

f_{bu} = the number of times that R_b is placed in category S_u,

and $f_{a<u}$ = the number of times R_a is placed in categories lower than S_u.

Then $f_{bu}f_{a<u}$ = the number of times that R_b, when placed in category S_u, is judged distinctly greater than is R_a.

When R_a and R_b are placed in the same class S_u, there are $f_{au}f_{bu}$ comparisons, one half of which are assumed to yield judgments of the type $R_b > R_a$. This adds $\frac{1}{2}(f_{au}f_{bu})$ to the total number of times R_b is judged greater than R_a. So far as class S_u is concerned, then, the number of judgments of $R_b > R_a$ is given by the equation

$$\begin{aligned} C_{(b>a)u} &= f_{bu}f_{a<u} + \tfrac{1}{2}(f_{bu}f_{au}) \\ &= f_{bu}(f_{a<u} + \tfrac{1}{2}f_{au}), \end{aligned}$$

in which $C_{(b>a)u}$ stands for the number of choices given to R_b in preference to R_a considering only the data of category S_u. Summing for all categories in which judgments of R_a and R_b appear,

$$C_{b>a} = \Sigma[f_{bu}(f_{a<u} + \tfrac{1}{2}f_{au})]. \qquad (1)$$

The total number of times that R_b is conceived as having been compared with R_a is equal to N^2, where N is the total number of times every stimulus is judged. That is to say, every placement of R_b is thought of as representing in turn a comparison with every placement of R_b. The N^2 'judgments' are comparative judgments by inference only. They might be called 'pseudo-comparative' judgments. But it is the assumption of this scaling method that they may be treated statistically as if genuine comparative judgments had been made. It is assumed, further, that Thurstone's law of comparative judgment may be applied and consequently the usual approach to the extraction of scale separations may be employed. The proportion of the N^2 judgments that are of the type $R_b > R_a$ is given by the equation

$$p_{b>a} = \frac{\Sigma[f_{bu}(f_{a<u} + \tfrac{1}{2}f_{au})]}{N^2}. \qquad (2)$$

Dividing the right side of equation (2) through by N^2, we have

$$p_{b>a} = \Sigma\left[\frac{f_{bu}}{N}\left(\frac{f_{a<u}}{N} + \frac{f_{au}}{2N}\right)\right]. \qquad (3)$$

Now $\frac{f_{bu}}{N} = p_{bu}$, the proportion of the judgments of R_b that occur in position S_u,

$\frac{f_{a<u}}{N} = p_{a<u}$, the proportion of the judgments of R_a placing it below S_u,

and $\frac{f_{au}}{N} = p_{au}$, the proportion of the judgments of R_a that occur in position S_u.

Substituting these proportions in equation (2), we have

$$p_{b>a} = \Sigma[p_{bu}(p_{a<u} + \tfrac{1}{2}p_{au})]. \qquad (4)$$

As a matter of practical convenience, it is well to begin the computation of the proportions $p_{b>a}$ by determining for every cell in the table of data the value of $(p_{a<u} + \frac{1}{2}p_{au})$. This value remains the same for use no matter with what stimulus one is comparing R_a. One may find it more convenient to work with formula (2) than with formula (4). In this case the corresponding value $(f_{a<u} + \frac{1}{2}f_{au})$ is the one to compute for every cell.

To illustrate the procedures thus far, let us use a fragment of the data found in the writer's *Psychometric Methods*, page 164.[1] The stimuli were 23 cards containing varying numbers of the letter 'o' scattered evenly over an area 2.5 inches square, the number of 'o''s ranging from 15 to 74. The cards were judged by placing them in nine equidistant piles in 40 different trials. Consider only the data pertinent to the comparison of the cards with 17 and 20 letters on them. These data may be arranged as in Table I. The cell frequencies are dealt with here and formula (2) is employed rather than formula (4) because smaller numbers may then be used.

The deviate corresponding to this proportion is + .426, which is the scale separation between R_{20} and R_{17} in terms of the standard error of the difference. Other scale separations

[1] J. P. Guilford, *Psychometric Methods*. N. Y.: McGraw-Hill Book Company, Inc. 1936.

TABLE I

AN EXAMPLE OF THE COMPUTATION OF A PROPORTION FROM JUDGMENTS IN ABSOLUTE CATEGORIES

S_u	f_{au}	$f_{a<u}$	$\frac{1}{2}f_{au}$	$(f_{a<u} + \frac{1}{2}f_{au})$	f_{bu}	$f_{bu}(f_{a<u} + \frac{1}{2}f_{au})$
1	7		3.5	3.5	3	10.5
2	18	7	9.0	16.0	12	192.0
3	11	25	5.5	30.5	14	427.0
4	4	36	2.0	38.0	3	114.0
5	0	40		40.0	6	240.0
6	0	40		40.0	2	80.0

$N^2 = 1600$ $\Sigma = 1063.5$

$$p_{20>17} = \frac{1063.5}{1600} = .665.$$

are estimated in a similar manner and treated as in the method of paired comparisons.[2]

COMPARISONS WITH A COMPOSITE STANDARD

As a second procedure, let us begin with the assumption that when any stimulus is placed in a category S_u it is judged distinctly greater than all stimuli, including itself, placed in categories lower than S_u and in addition it is judged greater than half the stimuli in position S_u, including itself. The entire set of stimuli then constitutes a composite standard with which each stimulus is compared. Let

f_{au} = the number of times R_a is placed in position S_u, as before,

$F_{k<u}$ = the number of times all stimuli are placed in positions below S_u, including R_a,

and F_{ku} = the number of times all stimuli are placed in position S_u, including R_a.

By analogy to equation (1), we may state the following definition of the number of choices of R_a when compared with the composite standard of all the stimuli combined.

$$C_{a>cs} = \Sigma[f_{au}(F_{k<u} + \tfrac{1}{2}F_{ku})]. \qquad (5)$$

The proportion of the time that R_a is judged greater than the

[2] For a summary of the paired comparison techniques see the author's *Psychometric Methods*, Ch. 7.

composite standard is

$$p_{a>cs} = \frac{\Sigma[f_{au}(F_{k<u} + \frac{1}{2}F_{ku})]}{nN^2}, \tag{6}$$

in which n is the number of categories in which any of the stimuli appear. The expression nN^2 is the total possible number of comparisons. Dividing numerator and denominator through by nN^2,

$$p_{a>cs} = \Sigma\left[\frac{f_{au}}{N}\left(\frac{F_{k<u}}{nN} + \frac{F_{ku}}{2nN}\right)\right]. \tag{7}$$

But $\frac{f_{au}}{N} = p_{au}$, $\frac{F_{k<u}}{nN} = p_{k<u}$, and $\frac{F_{ku}}{nN} = p_{ku}$. We can therefore write the equation as

$$p_{a>cs} = \Sigma[p_{au}(p_{k<u} + \tfrac{1}{2}p_{ku})]. \tag{8}$$

The writer has found the most convenient formula to be

$$p_{a>cs} = \frac{\Sigma[f_{au}(p_{k<u} + \frac{1}{2}p_{ku})]}{N}. \tag{9}$$

The solution of the scale value for R_{20} as in Table II may be used as an example of this procedure.

TABLE II

THE SOLUTION OF A SCALE VALUE BY THE ASSUMPTION OF A COMPOSITE STANDARD

S_u	F_{ku}	$\frac{1}{2}F_{ku}$	$F_{k<u}$	$(F_{k<u}+\frac{1}{2}F_{ku})$	$(p_{k<u}+\frac{1}{2}p_{ku})$	f_{au}	$f_{au}(p_{k<u}+\frac{1}{2}p_{ku})$
1	49	24.5		24.5	.027	3	.081
2	101	50.5	49	99.5	.108	12	1.296
3	83	41.5	150	191.5	.208	14	2.912
4	133	66.5	233	299.5	.326	3	.978
5	141	70.5	366	436.5	.475	6	2.850
6	135	67.5	507	574.5	.625	2	1.250

$\Sigma = 9.367$

$$p_{a>cs} = \frac{9.367}{40} = .234.$$

The corresponding deviate is $-.726$. The remaining 22 stimuli may be evaluated in a corresponding manner. To make all values positive we may add a constant amount to them.

An Absolute Scaling Method

This procedure has been called an 'absolute scaling method' because of its parallel with a method by the same name used in the measurement of item difficulty in mental testing.[3] There is nothing in judgments by equal appearing intervals, or in rating scale methods, that enables us to 'score' a judgment as right or wrong and so to determine the number of successes and of failures for a response. Yet there is an analogy that can be supported and the mechanics of the method of scaling that I am about to propose is almost identical with that of the scaling of test items.

Whenever O places stimulus R_a in category S_u, we may not say that he has succeeded or failed, but we may say that the stimulus itself has 'succeeded' in attaining a certain standard of psychological value and in exceeding all standards below S_u. Class S_u then represents a given standard of excellence or of quantity for a stimulus; the stimulus in fact has at the moment an amount of size that surpasses all classes below S_u. We should add here the assumption that the categories themselves remain invariant regardless of what stimuli are at the moment being placed in them. This assumption will bear further examination on theoretical grounds, but it will serve for the present for practical purposes. From the proportion of the times that any stimulus R_a exceeds a given class we can determine its linear distance from that class level by means of the deviate corresponding to that proportion. Let this deviate be designated by X_{au}. The deviation of another item, R_b, can be measured from the same class level. Let this be known as X_{bu}. The scale separation between the two stimuli would then be measured by the difference $X_{bu} - X_{au}$. In a similar manner we can determine distances of the same two stimuli from another common class level, let us say S_v. The difference $X_{bv} - X_{av}$ is another estimate of the scale separation between the impressions of the two stimuli. A number of these estimates of the same scale separations can thus be made and a mean

[3] For a brief resume of the absolute scaling of test items see the author's *Psychometric Methods*, pp. 438–444.

of them may be taken as the most accurate measurement of it. Naturally, closely neighboring stimuli on the scale will have in common a larger number of classes and so more single estimates of scale separations can be made between them than between remote pairs. To illustrate the procedure, in Table III are given a section of the same data from which examples have been drawn to demonstrate the other two procedures.

TABLE III

DATA TO ILLUSTRATE THE ABSOLUTE SCALING PROCEDURE WITH JUDGMENTS IN ABSOLUTE CATEGORIES

R_k	Proportions of the Times the Stimuli Exceed the Categories					Deviates of the Stimuli from the Category Values				
	S_u 1	2	3	4	5	1	2	3	4	5
15	.650	.200	.025			.385	− .842	−1.960		
16	.600	.125	.050			.253	−1.150	−1.645		
17	.825	.375	.100			.935	− .319	−1.282		
19	.800	.350	.125	.050		.842	− .385	−1.150	−1.645	
20	.925	.625	.275	.200	.050	1.440	.319	− .598	− .842	−1.645

For stimuli R_{19} and R_{20} we can extract four scale separations in the table of deviates at the right. They are .598, .704, .552, and .803, from left to right, respectively. The mean of the four is .664 and this may be taken as the best measurement of the scale separation in question. Other separations between neighboring pairs of stimuli are similarly determined. A value of zero may be assigned to the lowest stimulus in the series and then the other stimuli are evaluated with reference to this zero point.

There is another very interesting application of this method, and that is to determine by absolute scaling the distances between the categories of *O*'s scale of supposedly equal appearing intervals. This can be done from the table of deviates in Table III above. There are five estimates of the psychological distance between categories S_1 and S_2 in the sampling of data that we have here. They are, reading from top to bottom, 1.227, 1.403, 1.254, 1.227, and 1.121, respectively. Their mean is 1.246. This absolute amount should not lead us to suppose that instead of the unitary distance

between classes one and two the observer has introduced 1.246 units. The unit of the absolute scale is not necessarily the same as that of equal appearing intervals. When the complete data were treated in this manner, it was found that the total range of absolute values was 8.521 whereas the total range of the scale distances by using medians was only 6.56. Making allowance for this difference in unit, we find that the scale separations between neighboring categories from one to eight were: 1.04, .76, .82, .91, .93, 1.48, and 1.07, respectively. If we are to place our faith in the absolute method in preference to the use of the median scale values, then instead of assigning the simple integers to *O*'s first eight categories, we should use the values: 1.00, 2.04, 2.80, 3.62, 4.53, 5.46, 6.94, and 8.00. The absolute separation between categories 8 and 9 is indeterminate, since no judgments exceeded category 9. Such a checking-up on actual scale separations between categories would tell us definitely about any distortions that the *O* or *O*s had introduced into any part of the scale, whether in judgments by equal appearing intervals, by rating scales, or by any other type of 'absolute' judgments. The discussion to follow will throw some doubt upon this procedure, however, and leave us perhaps a little undecided as to whether scale values by medians of category numbers or by other scaling methods give the truest picture of psychological separations.

A Comparison of the Methods

By way of comparison of the three new scaling devices here introduced with each other and with the use of medians, Fig. 1 has been drawn. On the abscissa are plotted the scale values as obtained by assuming comparative judgments and the application of Thurstone's law of comparative judgment, and his Case V. It is clear from the curves that the functional relationships between scale values both by assumption of a composite standard and also by absolute scaling with those by paired comparisons are linear. The regression of the medians on the scale values by paired comparisons is slightly but definitely nonlinear. By inference the medians also bear a nonlinear relationship to the other two sets of values.

There is a systematic shift in the unit of the scale of medians as compared with the other scales. This result checks with that of Hevner [4] when the stimuli were handwriting samples.

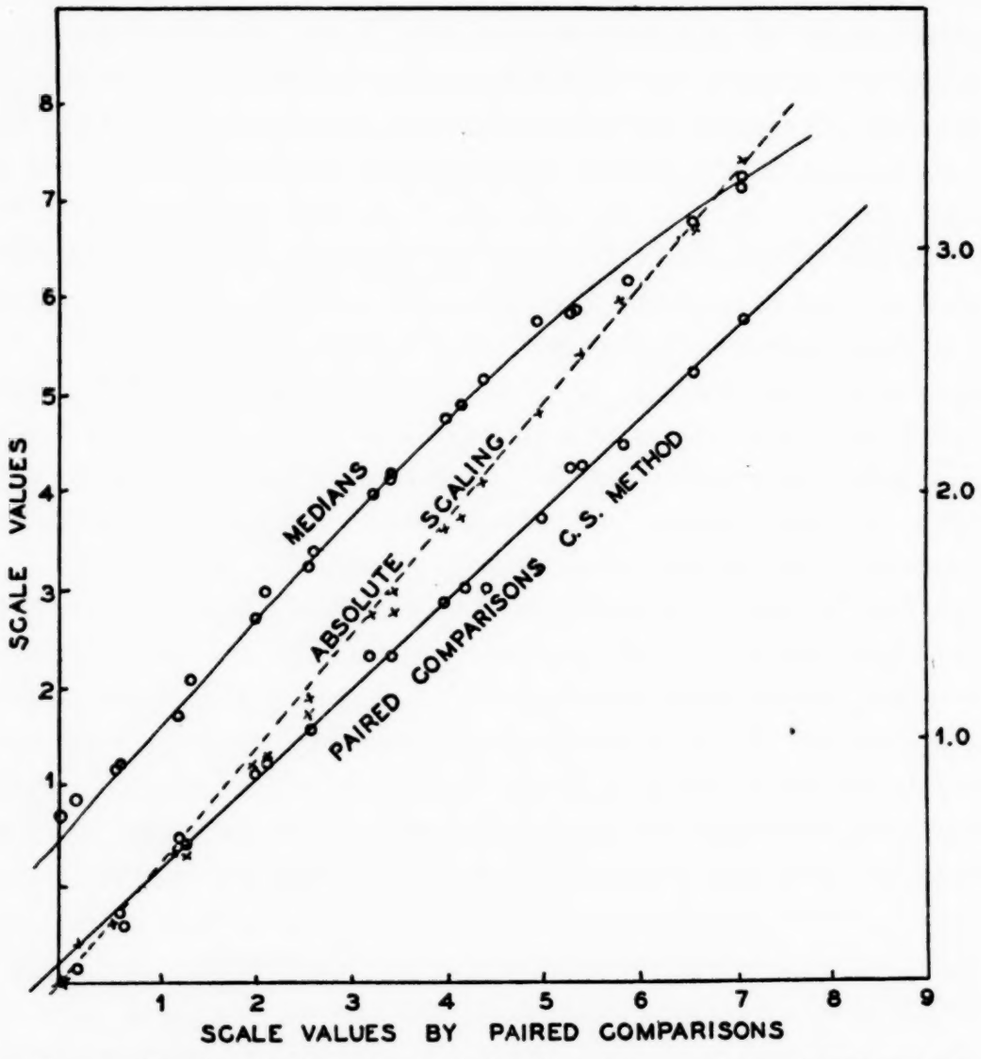

FIG. 1. Showing the functional relationships between the scale values derived from three scaling methods and scale values derived from the method of paired comparisons. The original data were obtained by the method of equal appearing intervals.

Her *O*s likewise failed to show as wide a discrimination among stimuli high on the scale as they did when judged by rank order or by paired comparisons.

Which of the methods are at fault? It is three against one, in this case, although it must be admitted that the three are similar basically in that the scale separations derive from

[4] K. Hevner, An empirical study of three psychophysical methods, *J. Gen. Psychol.*, 1930, 4, 191–212.

proportions of the times stimuli are judged greater than other stimuli or greater than common standards. But there is another, external, appeal. That is in the comparison of the scale values with log R, if we place credence in Fechner's law as applying to this type of stimuli. Figure 2 shows this

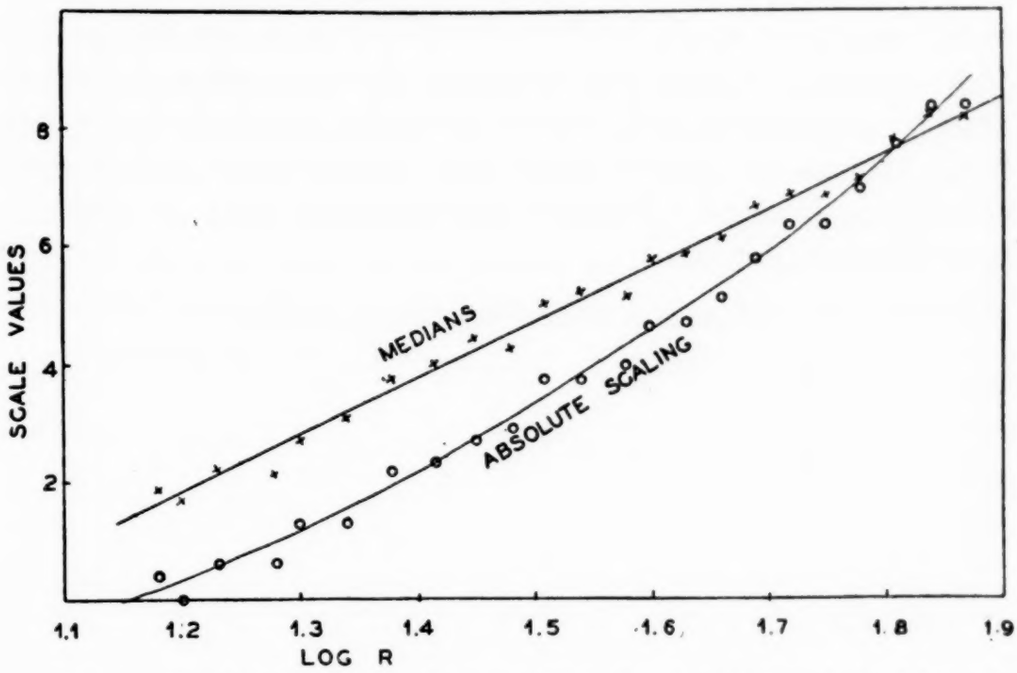

FIG. 2. Showing the functional relationships of scale values as derived from the direct use of medians and also from the method of absolute scaling and the logarithms of the stimuli. The data were obtained by the method of equal appearing intervals.

relationship between S and log R for the medians and for the absolute scaling method as a representative of the three that give concordant results. Here the medians definitely show a linear relationship, fulfilling Fechner's law; the absolute scaling method does not, and by inference, neither will the other two methods. Not knowing whether or not Fechner's law *does* apply to these stimuli, and not being able to obtain a unanimous answer experimentally on this question when different scaling methods are used, we are left in something of a quandary. Placing our faith in the methods that scale by way of comparative judgments, we might both reject Fechner's law as applying here and also reject medians as giving rational measurements on a scale of equal units. Indeed, the inequality that was revealed in addition to the systematic

change in unit with the level of the scale, when absolute scaling was employed, lends skepticism to the acceptance of 'equal appearing intervals' as being really equal. On the other hand, if we are convinced that Fechner's law should hold here, then we are bound to look for the implied weakness in values scaled from comparative judgments. This statement may also apply to data obtained from genuine paired comparisons. It may yet be shown that judgments by equal appearing intervals give values on scales relatively more free from systematic errors than will comparative judgments, genuine or implied. Further experimental work is essential to settle this question.

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SOME CONSTANT ERRORS IN RATINGS

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As experimental psychology in general becomes more quantitative the use of rating scale methods becomes increasingly important. Those investigators who are more critical of their techniques have from time to time pointed out obvious weaknesses in rating scales, and occasionally they have suggested remedies, though no one has made an intensive

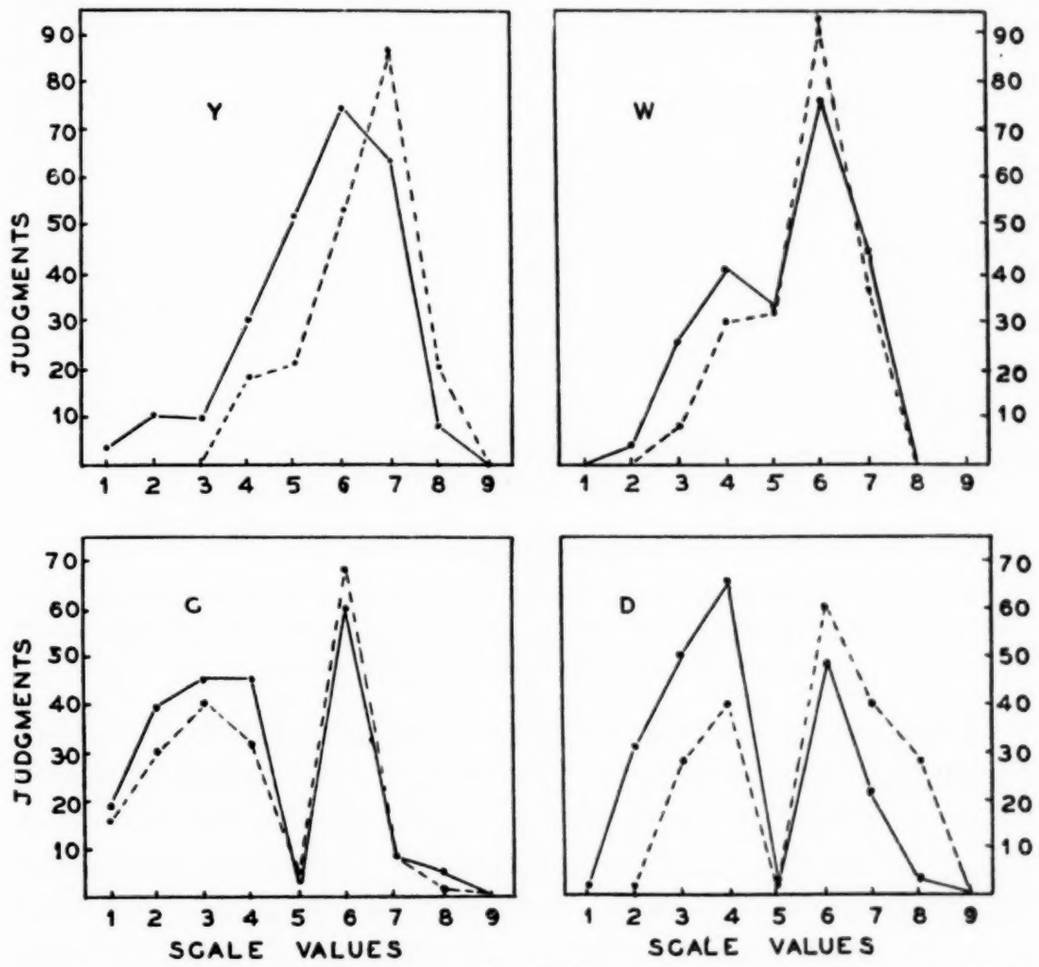

FIG. 1. Four typical frequency distributions of 200 ratings given by single observers to 40 single colors (solid lines) and of 225 ratings given by the same observers (dotted lines) to 45 color combinations in five trials. The ratings were for affective value on a numerical scale.

statistical study of those weaknesses. It is the purpose of this article to examine in particular some typical rating scales of affective value and to suggest a remedy for one of the common constant errors.

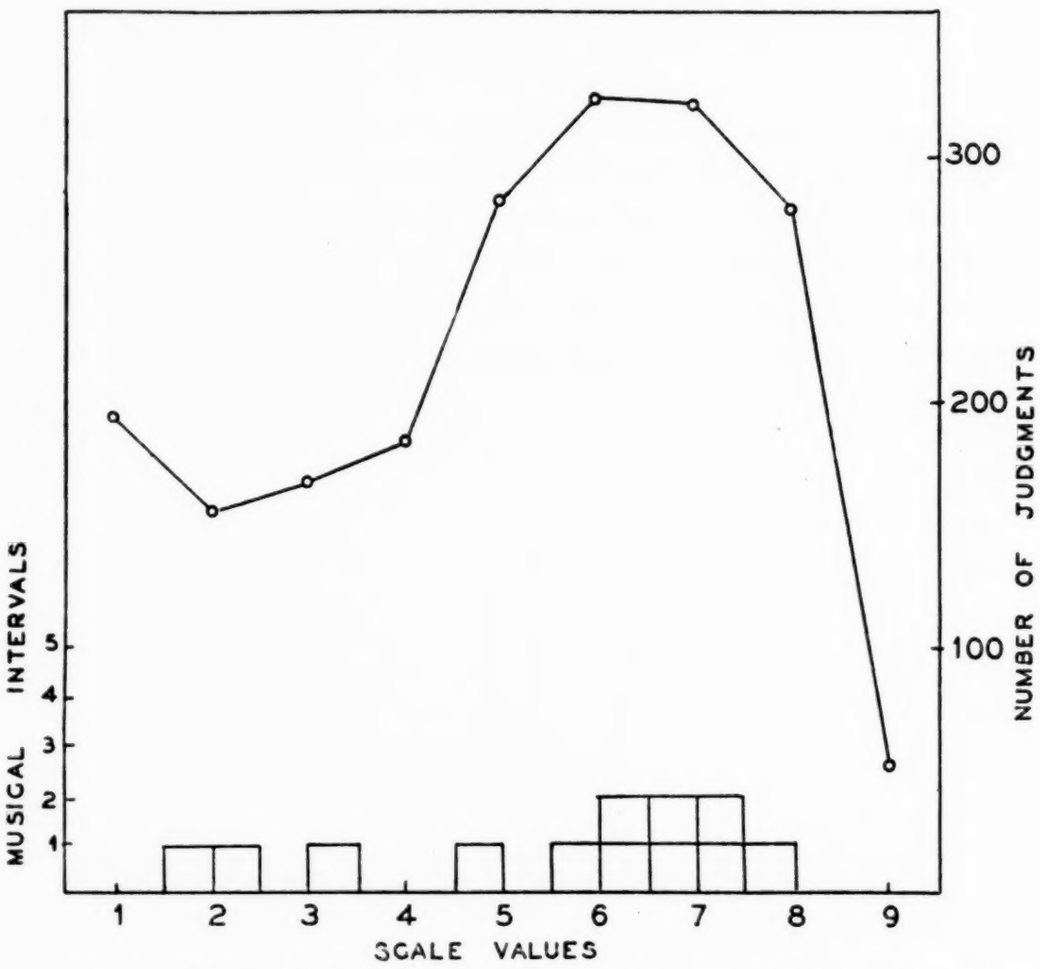

FIG. 2. The distribution of 12 musical intervals when rated for affective value and the frequency distribution of 1873 ratings assigned to them by 157 observers in three trials. A graphic rating scale of the sectional type was used.

If one secures a large number of ratings of a set of stimuli from single observers and then plots the frequency distributions of the ratings, distribution curves of the type shown in Fig. 1 are the result. The rating scale from which the curves in Fig. 1 were derived was of the numerical variety, with nine categories described as follows: (1) extremely unpleasant, (2) very unpleasant, (3) moderately unpleasant, (4) mildly unpleasant, (5) indifferent, (6) mildly pleasant, (7) moderately pleasant, (8) very pleasant, and (9) extremely pleasant. The

stimuli were: (1) a set of 40 single colors, and (2) a set of 45 color combinations. Both sets were rated on five different occasions by the same *O*, making 200 ratings of the single colors and 225 of the color combinations. Two striking facts

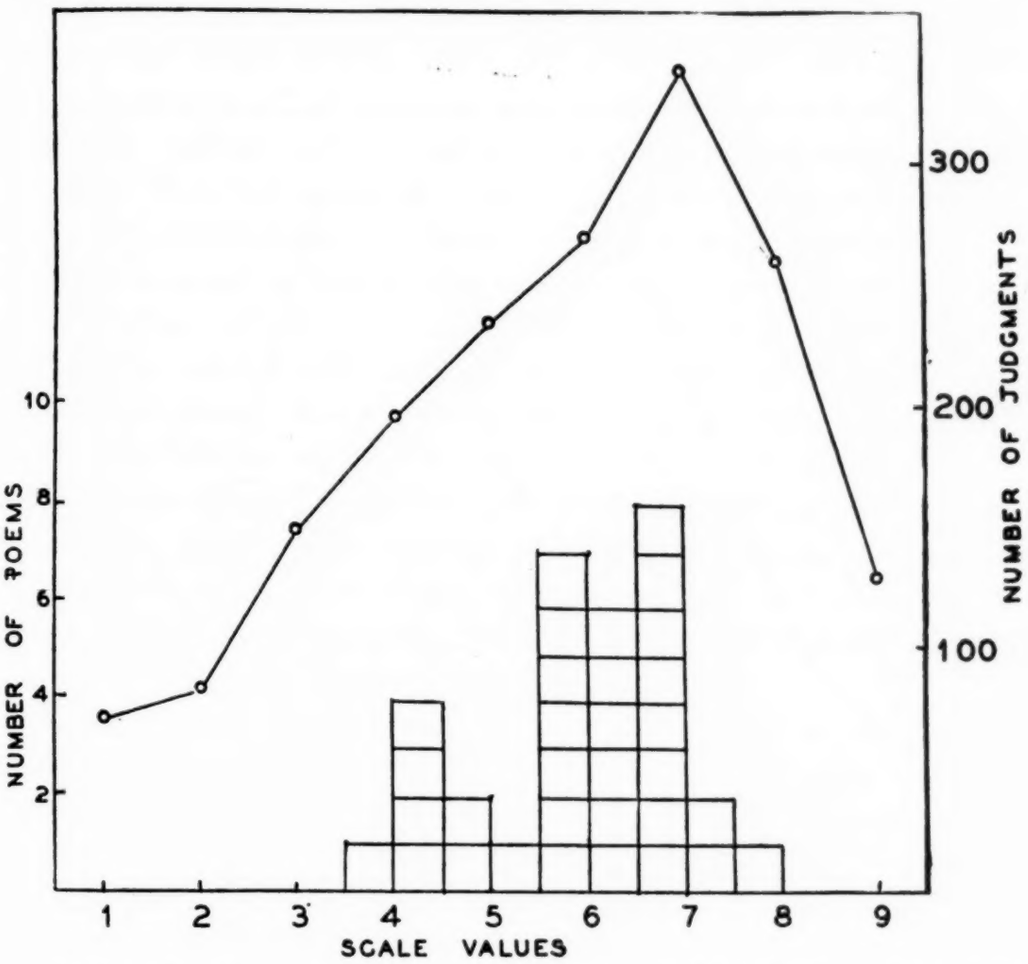

FIG. 3. The frequency distribution of 32 poems rated for affective value and the frequency distribution of 1728 ratings assigned to them by 27 observers in two trials. A graphic rating scale of the sectional type was employed.

stand out in these distribution curves: One is the fact that many of the distributions are unimodal, approaching the normal curve in form, whereas others are distinctly bimodal, with a dearth of ratings in the 'indifferent' category. The second fact is that for the same individual the shape of the curve is decidedly constant whether he is rating colors or color combinations. Incidentally, if any *O*'s ratings for either colors or for color combinations are divided into two random pools, his two distributions retain the same striking similarity in form.

In attempting to interpret these facts we face the difficulty of not knowing precisely what the distribution of actual affective values is like. The nearest we can come to a knowledge of this distribution is to find for every stimulus the mean or median of a large number of individual ratings from different *O*'s. At first thought one might expect a distribution of

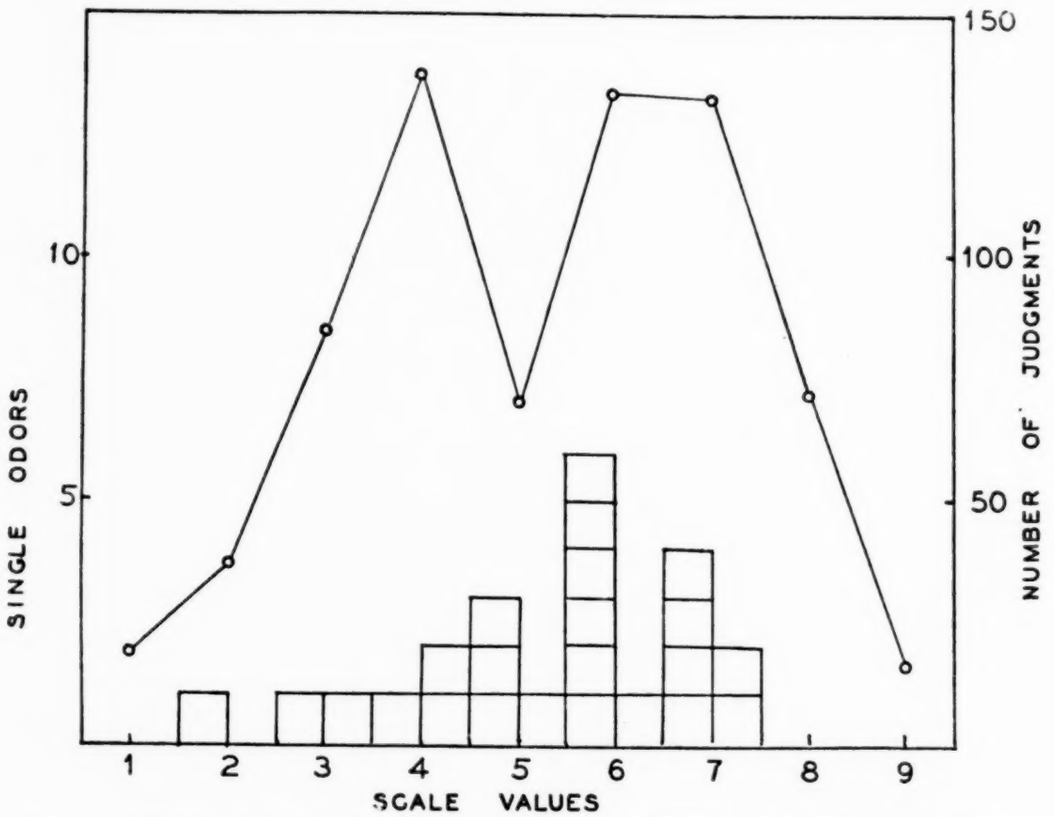

FIG. 4. The distribution of 23 single odors along the affective scale and the frequency distribution of 684 ratings assigned to them by eight observers on a numerical scale.

such values to reflect clearly the form of distribution of individual ratings. A comparison of the two distributions for the sake of drawing conclusions about constant errors in individual observers would then be in a class with trying to lift oneself with one's own bootstraps. The situation is not quite so hopeless as this, as subsequent discussion will show. In general, it can be said that the form of the distribution of the mean affective values, whether unimodal or bimodal, does not necessarily follow the form of the distributions of the single ratings when pooled (see Figs. 3 and 4).

Three Hypotheses

Without any knowledge of the form of distribution of the actual affective values, we may set up three hypotheses to account for the facts standing out in Fig. 1 and then see whether such facts as we have support any of these hypotheses. We might begin with the assumption that any set of stimuli selected at random and without knowledge of their affective values are actually normally distributed. This assumes that the universe from which they are chosen is also normally distributed and postulates a general psychological law. The general law would be that for any class of stimuli, colors, odors, drawings, samples of handwriting, and the like, there is a modal affective value (not necessarily at the indifference point) and that the frequency of stimuli drops off symmetrically on either side of this value. When the stimuli are human creations, as for example, handwriting samples or drawings, such an assumption is justified from the sheer accumulation of facts about human abilities and their products. When the stimuli are not human productions, the assumption needs further empirical support.

For our first hypothesis we need not go far as to assume that the actual distribution is normal; it need only be unimodal. Should the mode of any class of stimuli be near the upper or lower end of the affective scale, the distribution would probably be skewed. How, then, shall we account for the individual differences such as we find in the distributions of single judgments in Fig. 1? Under hypothesis *I* the unimodal distributions yielded by some of the *O*s must be assumed to reflect the real distribution. The bimodal distributions, which are the prevailing type when numerical scales are used, must then reflect some peculiarity of the observers. Since, with very few exceptions this bimodality comes about because of the dearth of ratings in the 'indifferent' category, we may assume that when a numerical scale is used many *O*s are taking that category as a point rather than as a unitary section of the affective scale. Such a tendency cannot be conceived as complete, however, for many *O*s give a significant number of judgments in that category, and very rarely indeed

does an *O* place none at all in it. The correct statement would be that many *O*s introduce a contraction into their own affective scales in the region of indifference when the scale as set up by the experimenter was intended to allow a full unit's space to the judgment 'indifferent.'

Since the majority of the *O*s yielded bimodal distributions, however, we must not overlook the hypothesis that sets of stimuli selected at random do in reality fall into bimodal distributions. This implies a different general law of affective life; that the natural attitude attempts to dichotomize experiences, avoiding the indifferent and the mediocre in affective reactions. In this case, the majority of the *O*s reflect the real distribution when they yield bimodal distributions of judgments and they are not making a personal distortion of the rating scale. The *O*s who yield unimodal distributions of judgments under hypothesis *II* are guilty of distorting the rating scale in a different manner; they extend the small 'indifferent' category (or any category at which the gap actually occurs) to include judgments that should have gone into neighboring classes. This might be conceived as a case of the error of central tendency in human judgment.

Still a third hypothesis might be that whatever the actual distribution, every *O* has certain predilections for using or not using certain categories. Regardless of the actual distribution, and with relatively small samples this might vary in heterogeneous ways in different sets of stimuli, *O* tends under this hypothesis to maintain his own peculiar type of distribution, whether unimodal, or bimodal, skewed in one direction or the other, or whether possessing other idiosyncracies. The close duplication of curves from the same *O* as in Fig. 1 suggests this possibility. No two unimodal curves from different *O*s are just alike and no two bimodal curves from different *O*s are just alike when rating the same stimuli. In many details, in addition to the number of modes, the distributions of the same *O* even with different sets of stimuli are strikingly similar. Each *O*, under this hypothesis, has his own peculiar attitude toward affective stimuli in general, or toward the affective rating scale, or has his own habits of scalar distortion.

Some Typical Results with Rating Scales

Some data that bear upon these three hypotheses will now be presented. They are summarized in Table I.[1] They

TABLE I

A Comparison of the Types of Distribution of Stimuli with the Types of Distribution of Judgments Given by Single Observers

Type	Stimuli			Judgments			*Os*
	Number	Type of Scale	Type of Distrib.	Number	Proportion of Distributions		N
					Unimodal	Bimodal	
Musical intervals . .	12	Sectional graphic	Bimodal	36	.182	.818	121
Musical intervals . .	12	Continuous graphic	Bimodal	36	.306	.694	36
Poems	32	Sectional graphic	Unimodal ?	64	.518	.482	27
Odors	23	Numerical	Unimodal	88	.250	.750	8
Odor combinations .	42	Numerical	Unimodal	84	.375	.625	8
Colors	40	Numerical	Unimodal	200	.400	.600	10
Color combinations	45	Numerical	Unimodal ?	225	.300	.700	10
Colors	211	Numerical	Unimodal	422	.425	.575	40

were not collected for the distinct purpose of testing the three hypotheses stated above. Obviously, for this purpose the same *O*s should be used with several types of stimuli and with several types of rating scales with the same set of stimuli. When we point out, as we shall, certain constant differences between graphic and numerical scales we must rest upon the faith that comparable groups of human *O*s were employed in the two cases. With but four exceptions out of 260 *O*s they were undergraduates and would be considered naive to the observational tasks. In this respect, at least, they were comparable *O*s.

There were two kinds of graphic scales used in securing the ratings of musical intervals and poems. The 'sectional' graphic used a horizontal line divided into nine equal parts, with the word 'indifferent' appearing at the middle and the

[1] We are indebted to Miss Elysbeth C. Allen, Willard Spence and Mrs. Jennie Cain for the rating scale data on poems, colors and odors and their combinations and to N. Y. A. student assistants who did much of the tabulating and the preparation of frequency distributions.

words 'pleasant' and 'unpleasant' at the two ends respectively. These words each extended beyond single units and so merely defined the scale as a whole. The 'continuous' graphic was the same except that there was only one division point on the line, and that was exactly in the center, under the word 'indifferent.'

The first item of interest in Table I is the nature of the actual distribution of affective values for each set of stimuli. With the exception of the musical intervals the distributions are probably unimodal, although there is some doubt about the distributions in the case of the poems (see Fig. 3) and the color combinations. The 12 musical intervals include all the possible dyads in the musical scale. The intervals of major and minor second, and major and minor seventh are notably unpleasant whereas the remaining eight are pleasant for most *O*s. The distribution represented in Fig. 2 is therefore probably not far from the truth. It will be noticed in Fig. 2 that the total distribution of 1873 single judgments reflects fairly well this bimodality. Examining the 157 distributions of 36 judgments each we find that when the sectional graphic scale is used about 82 percent of them are bimodal and when the continuous graphic scale is used about 69 percent are bimodal. The difference between the two is probably not significant, but both show a preponderance of bimodal distributions. What can we say of the remaining 20 to 30 percent of unimodal distributions? They would support hypotheses *II* and *III*.

The distributions for the poems do not yield clear evidence bearing on the theories. In Fig. 3 we see that the 32 affective values may be unimodally distributed. Whether the depression in the region of 5 is a real division point between two modalities or whether it is simply an inversion is hard to say. The fact that these poems are the product of human ability and were randomly selected so far as affective value is concerned supports the belief that the real distribution should be normal, or at least unimodal. The distribution of the pool of all individual judgments is decidedly unimodal though skewed. The skewness may be a result of the fact that the

poems were for the most part selected from anthologies of published verse and have therefore passed one or more hurdles of human preference. It may be due in part to the fact that students rate poems higher than they really should because they are expected to like poetry. As far as possible the selections were unfamiliar and not 'classical' quotations. Of the 27 *O*s, about half of them yielded unimodal and half bimodal distributions. Taken by itself this result means very little. In comparison with the ratings of musical intervals on the same type of scale we note a material reduction in the proportion of bimodal distributions (from 82 percent to 48 percent) when we go from a set of stimuli known to be actually bimodal to a set that is probably unimodal in its distribution.

The actual distributions of odors and colors and of their combinations are generally unimodal, with some doubt about the distribution for color combinations. The distribution of single odors as seen in Fig. 4 is typical of this group in which a numerical scale was employed. In spite of this real unimodality, the distributions of all individual ratings pooled together are bimodal, and the majority of the individual distributions (about 60 to 70 percent) are bimodal as will be seen in Table I. The preponderance of bimodal distributions is not quite so great as in the case of the musical intervals where a sectional graphic scale was used with stimuli that are bimodally distributed, but it is consistently greater than for the poems in which case a graphic scale was used and a distribution of stimuli was unimodal though possibly bimodal in character. Perhaps the most convincing of all data are those from 211 color samples that were selected systematically from the Munsell Book of Color. They represent color in all its variations, in hue, tint, and chroma. The distribution of average scale values from 40 *O*s is unquestionably unimodal. Yet 23 of the 40 *O*s turned in distributions that are bimodal. One cannot escape the general inference that numerical scales predispose *O* to bimodal distributions regardless of the nature of the real distribution of stimuli whereas the graphic scales predispose *O* to distributions that agree in type with the real

distribution though they do not completely succeed in doing so.

To throw further light upon this difference between graphic and numerical scales, let us employ Table II. In this table

TABLE II

POSITIONS OF LOWEST FREQUENCY BETWEEN MODES IN THE INDIVIDUALS' DISTRIBUTIONS

Stimuli	Type of Scale	Lowest in Average *S*-Value between Modes	Number of Times Each *S*-Value is Lowest in Individuals' Distributions					
			2	3	4	5	6	7
Musical intervals . .	Sectional graphic	4	1	20	44	25	8	1
Musical intervals . .	Continuous graphic	4	1	9	10	3	2	
Poems	Sectional graphic	5 ?		2	5	6		
Odors	Numerical	–				6		
Odor combinations .	Numerical	–				4	1	
Colors	Numerical	–				6		
Color combinations	Numerical	5 ?			1	6		
Colors	Numerical	–			1	16		

an attempt has been made to see whether when an individual's distribution is bimodal, his lowest frequency between the two modes comes exactly at the indifference point, as hypothesis *I* implies with regard to those *O*s who yield bimodal distributions. Or will the point of lowest frequency come at any place, when the real distribution is unimodal? We can see, also, when the real distribution is bimodal, whether the individual's lowest category between modes coincides with the real one. We can compare the numerical and graphic scales as regards the location of the lowest frequencies.

To answer the last question first, we see in Table II that quite decidedly the category of lowest frequency is at or very near the indifference point or unit for the numerical scales whereas it scatters more widely over the scale for the graphic scales. For the graphic scales it scatters over the range whether the sectional or the continuous type is used. In the case of the musical intervals, from the nature of the real distribution we should expect the smallest frequency of ratings at step 4 on the scale. This expectation is more or less borne

out, but the lowest frequency also came at positions all the way from 2 to 7, with no undue increase at the indifference zone as the tendency in hypothesis *I* would predict. This scattering of the deficient category is due to positive or negative general constant errors. Some *O*s tend to place *all* musical intervals higher or lower on the scale than others, but most of them do appreciate a gap between the two groups of them. When the real distribution is unimodal the point of lowest frequency is likely to be at the indifference category and this tendency is decidedly more true when the numerical scale is used. For an unambiguous answer, however, we should have used both numerical and graphic scales with the same kind of stimuli.

The results have some bearing upon the three hypotheses that were proposed in the beginning, though they do not by any means prove one theory correct and the others false. It appears that when a relatively large sample of stimuli is selected from a given field the distribution will probably be unimodal, though it may be skewed, whether the stimuli are the result of human production or not. The mode may not be at the indifference point or zone. The distribution of 211 colors on the affective scale is the best proof of these assertions. Such conclusions definitely rule out the fundamental assumption of hypothesis *II*, though there may be exceptions. Some real distributions when not made at random or when based upon a very small number of stimuli, such as the distribution of the 12 musical intervals, may well be bimodal in form. When the real distribution is unimodal and when the rating scale is of the numerical type with one category labeled 'indifferent' a majority of the individuals will yield bimodal distributions with a scarcity of 'indifferent' judgments. The effect is a contraction of the scale in the region of indifference as if *O* took 'indifference' to be a point instead of an interval. This contraction is never complete, being only a tendency, but a tendency that is more or less constant for the individual regardless of the type of stimuli he is rating. Superimposed upon these constant tendencies are also other individual idiosyncracies. This is evident, not only in the

close similarity of pairs of curves from the same *O*s from the ratings of colors and color combinations as shown in Fig. 1, but also in the similar close resemblance of distributions from the eight *O*s who judged odors and odor combinations. These individual predilections include not only the most obvious tendencies such as the number of modes but also certain minor tendencies like skewness and general positive and negative errors. To sum up this paragraph, hypothesis *II* is rejected in favor of a combination of *I* and *III*.

A Technique for Correcting Ratings for Distortions of Scales

Since, with numerical scales, at least, the most common case seems to be a real unimodal distribution of stimuli with a majority of the *O*s avoiding the use of the 'indifferent' category, or other categories, some stock remedy is in order. It will not do to eliminate the low category entirely, assorting the few judgments in it equally among those on either side of it, for the reason that this tendency toward bimodality differs so much for different *O*s and is rarely if ever complete. To follow such a procedure would introduce as much distortion into the results as some of the *O*s already have done. We even find 25 to 40 percent of the *O*s who actually yield unimodal distributions. We therefore propose an alternative method which makes just as much correction as is necessary for each observer and which we believe will enable us to translate every *O*'s ratings into a new set of numbers such that the equality of his units is probably assured.

Let us assume that *O*'s ratings should be normally distributed had he not violated any part of the scale by avoiding a given category or categories. The problem is then to find a new set of *S*-values to replace the original ones in terms of which *O* gave his judgments such that the expected number of judgments occur at each new scale position. In other words, we wish to normalize the frequency surface that represents all *O*'s judgments. This can best be done by dealing with cumulative frequencies. The procedure is outlined in Table III. In this table, *S* stands for the upper limits of the class

TABLE III

THE CORRECTION OF THE RATINGS OF A SINGLE OBSERVER FOR DISTORTIONS FROM AN ASSUMED NORMAL DISTRIBUTION OF JUDGMENTS

S	*f*	*cf*	*p*	*z*	$z\sigma$	$z\sigma + (Mdn - .5)$	Original Ratings	Corrected Ratings
2.5	2	2	.01	−2.327	−3.8046	1.408	2	1.4
3.5	28	30	.15	−1.037	−1.6955	3.517	3	3.5
4.5	40	70	.35	− .385	− .6295	4.583	4	4.6
5.5	2	72	.36	− .359	− .5870	4.646	5	4.6
6.5	60	132	.66	.412	.6736	5.887	6	5.9
7.5	40	172	.86	1.080	1.7658	6.979	7	7.0
8.5	28	200	1.00	(1.476)	(2.4133)	(8.126)	8	8.1

intervals, *f* for the cell frequencies, and *cf* for the cumulative frequencies. Under *p* are the proportions of ratings up to the corresponding *S*-value. Under *z* are the corresponding deviates on the abscissa of the normal curve. The best-fitting ogive is determined by the method of least squares [2] without the use of Urban's weights. This omission is recommended because Urban's weights are greatest for proportions near .50 in which region in this case *O* has the greatest distortion in his distribution. From the constants of the equation $z = a + bS$ are determined the median and the standard deviation of the best-fitting curve. The constant b is given by the formula

$$b = \frac{N\Sigma(Sz) - (\Sigma S)(\Sigma z)}{N\Sigma S^2 - (\Sigma S)^2} \tag{1}$$

and a by the formula

$$a = M_z - bM_S. \tag{2}$$

The median is determined by the formula

$$Mdn = -\frac{a}{b} \tag{3}$$

and from the same equation for the regression of z upon S, assuming a perfect correlation, the standard deviation is given by the formula

$$\sigma = \frac{1}{b}. \tag{4}$$

For the data in Table III the median is 5.713 and σ is 1.635.

[2] For simpler, alternative solutions of this problem, see the senior author's *Psychometric Methods*, 1936, 294–297.

To find the corrected scale values we now ascertain how far from the median each category deviates. These deviations are given by the product $z\sigma$ and they will be seen in Table III. To make them comparable with the original ratings numerically we add to them the amount $(Mdn - .5)$. Eliminating all except one decimal place we have the list of corrected scale values as given in the last column of Table III. The highest category, in this case the one including the original ratings of 8, needs special treatment. Since the proportion for this class is 1.000, z is infinite. For the purpose of computing a finite value for this class near its midpoint, we make the assumption that the midpoint should lie at a deviate that splits the proportion of the ratings in this last class into two equal parts. In the last row of Table III are given these estimated values of z, σz, and the corrected scale value to correspond with the original rating of 8.

If it is desired to know what the corrected distribution will look like, and what the expected frequencies are at the original positions on the scale, this can be done as follows. First, find $(S - Mdn)$ for every original S-value. Find z', which equals $(S - Mdn)/\sigma$. Find p' from the tables of the normal curve. Find cf' which equals Np', and finally, find f' by computing successive differences. The distribution of expected frequencies is assumed to be the one that O would have given had he not been predisposed to distort the rating scale.

It should be said again that this procedure may be employed only when there are good reasons to believe that O would have given a normal distribution of ratings had he not introduced distortions into his conception of the scale. In view of the experiences related in this article, it is most adaptable when numerical scales are employed, but it may be used also with graphic scale data. In another article one of us will propose three additional procedures for extracting from ratings, of any type, scale values that more certainly lie on scales of equal units; procedures that are applicable not only to ratings but also to judgments by the method of equal appearing intervals and the method of single stimuli.

These additional procedures rest upon the assumptions of comparative judgments and so being of a different character than the one proposed here will be reserved for a separate discussion. Since the assumption of normal distributions of ratings cannot always be made, the normalizing process here suggested has a more limited application than the other three methods. It will serve well in the cases for which it is prescribed.

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SALIVARY SECRETION DURING HYPNOSIS

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The primary purpose of this investigation was to discover the effect of hypnosis upon the unconditioned secretion from the parotid gland in adult human beings. We know of no other extensive studies of salivary secretion under hypnosis. According to Razran (**6**), Nevsky and Levine observed that in a nine year old child the salivary secretion accompanying the eating of various foods was approximately the same during hypnosis as in the normal state. Bramwell (**1**) mentioned a case of diminished salivation during the extraction of a tooth under hypnosis. Winsor (**8**) noted a reduction in amount of salivation upon the assumption of a reclining position and during sleep. Jenness and Wible (**5**), after reviewing the literature on the subject, concluded that in general the principal physiological functions show the same characteristics in hypnosis as in comparable normal waking states.

Subjects, Apparatus and Procedure

The subjects of the present experiment, six men and three women, were students at the University of Nebraska. Prior to the investigation, the women and three of the men had been hypnotized and had exhibited symptoms of visual hallucinations and of post-hypnotic amnesia for selected events of the hypnotic period. The other two men, who had shown no symptoms of hypnosis after long and repeated attempts to hypnotize them, were included as control subjects.

The experiment was conducted in a comparatively quiet room approximately nine feet square and ten feet high. The door of the room, which led into another closed room, was left ajar. Although there was little interference from outside noises, the conditions were not of the ideal type which Pavlov demanded for his dogs.

The apparatus for recording salivation was a modification of that described by Richter and Wada (**7**). Instead of the silver suction disk which they adapted from Lashley's saliometer, we used one of light hard rubber composition.[1] Suction for holding the inner cup over Stenson's duct was maintained by a heavy-walled rubber syringe bulb connected by rubber tubing with the outer disk of the saliometer. To

[1] We are greatly indebted to Dr. B. L. Hooper, Professor of Prosthetic Dentistry, University of Nebraska, for the manufacture of this device, which is more comfortable and practical than the silver saliometer.

deliver a specific amount of liquid stimulus to the subject's mouth without warning, we added to the apparatus the barrel and plunger of an ordinary glass hypodermic syringe of 10 cubic centimeters capacity. Attached to this was a long rubber tube, one-eighth inch in diameter, which was inserted in the subject's mouth with the tubing of the saliometer. The apparatus, except the saliometer tubing and the tube used in giving the stimulus, was hidden from the subject by a cardboard partition.

Each experimental session included an hypnotic period and a control waking period. The control period included three five-minute intervals of secretion, each preceded by one cubic centimeter of freshly prepared unsweetened lemon juice. The hypnotic period included two five-minute intervals, each following a stimulation of one cubic centimeter of lemon juice. To balance the order of procedure, one half of the control periods preceded the hypnosis and the other half followed hypnosis. The ABBA order was used with three of the hypnotized subjects, and the BAAB order with the other four. On an A day, the normal state preceded hypnosis; on a B day, the hypnotic period came first.

Upon being brought into the experimental room, the subject was seated in a comfortable Morris chair. Hypnosis was induced by asking the subject to close his eyes and to imagine how it would feel to go into a deep sleep.[2] Suggestions of relaxation and sleep were given for several minutes, the length of time spent in giving the suggestions depending upon the ease with which hypnosis was induced. Records of secretion for the hypnotic condition were not taken until after the subject had reported a specific visual hallucination suggested by the experimenter. The subject was at rest while the records for hypnosis were taken and suggestions of sleep and relaxation were repeated about once a minute during that time. After being dehypnotized, the subject was tested for amnesia for an event of the hypnotic period. Symptoms of amnesia were obtained in all cases. The subjects were asked to remain as quiet as possible at all times and to talk only when answering questions addressed to them. No other directions were given, except those involved in the hypnotic technique. No warning or signal was given to announce the coming of the stimulus. The subjects always rested in the Morris chair at least five minutes before any record was taken, the interval depending upon how long it took to adjust the apparatus.

The control subjects agreed to cooperate in simulating hypnosis. Suggestions of sleep and relaxation were given them for five minutes, after which the records were taken. At the conclusion of the records catalepsy of the eyelids was suggested to them very emphatically. In every instance the two subjects were able to open their eyes in spite of the suggestion that they would be unable to do so. However, Subject I sometimes opened his eyes slowly and with considerable effort. The remainder of the procedure for the control subjects was virtually the same as that for the hypnotized subjects.

Results and Discussion

For the purpose of comparison only the first two five-minute intervals of secretion of the normal records were used. Twenty-six of the twenty-eight daily records show less saliva secreted under hypnosis than in the normal state. The critical ratios (diff./σ diff.) for these reductions vary from

[2] Mr. Jenness acted as hypnotist and gave all suggestions. Salivary secretion was recorded by Mr. Hackman.

− 1.481 to 4.111. Three critical ratios were above 3.000, six between 2.000 and 3.000, thirteen between 1.000 and 2.000, four between 0.000 and 1.000 and two were negative. The two cases in which there was a reversal of the general trend involved unusual conditions on the part of the subjects concerned. The rank order coefficients of correlation between the hypnotic and normal daily records vary from .18 to .92, and the percentages of reduction vary from a negative 35 percent to 90 percent. Both the absolute and relative

TABLE I

CUBIC CENTIMETERS OF SECRETION FROM LEFT PAROTID GLAND OF SUBJECT E FOR TWO FIVE-MINUTE PERIODS OF NORMAL STATE AND TWO FIVE-MINUTE PERIODS OF HYPNOSIS ON FOUR DIFFERENT DAYS

	Normal	Hypnotic	Normal	Hypnotic
	A Day		*B* Day	
	First Stimulation		First Stimulation	
1st minute	.629	.750	1.394	.723
2nd minute	.338	.102	.284	.342
3rd minute	.299	.036	.330	.138
4th minute	.148	.065	.349	.168
5th minute	.885	.046	.638	.170
	Second Stimulation		Second Stimulation	
1st minute	1.533	.566	1.926	.741
2nd minute	.144	.304	.852	.406
3rd minute	.160	.121	1.012	.243
4th minute	.066	.080	.638	.150
5th minute	.304	.041	.639	.102
Average	.448	.211	.806	.318
Diff.	1.491		3.437	
$\frac{\text{Diff.}}{\sigma \text{ diff.}}$				
	B Day		*A* Day	
	First Stimulation		First Stimulation	
1st minute	1.284	.780	3.664	1.314
2nd minute	.343	.658	1.386	.109
3rd minute	.226	.559	.434	.287
4th minute	.143	.044	.405	.066
5th minute	.808	.031	.321	.119
	Second Stimulation		Second Stimulation	
1st minute	1.114	1.369	2.225	.496
2nd minute	.308	.020	.673	.083
3rd minute	.163	.043	.184	.044
4th minute	.187	.012	.328	.122
5th minute	.996	.020	.556	.034
Average	.557	.354	1.002	.268
Diff.	1.293		2.191	
$\frac{\text{Diff.}}{\sigma \text{ diff.}}$				

amounts of saliva varied greatly from subject to subject and from day to day for the same subject.

Table I shows a typical record of one subject for the four days. Only the first two periods for the normal state are included. Table II summarizes the pooled data for each individual subject and also the pooled data for all seven hypnotizable subjects. Data for the control subjects are treated individually at the end of the table. One may notice that in the records of the seven hypnotized subjects the differences between the means in five cases yield critical ratios above 3.000. The lower critical ratios represent subjects who at one session had an increased secretion during hypnosis. The Pearson r's between the minute by minute records in the two types of session range between .402 and .863. Each of these coefficients is more than 4.5 times its probable error. The percentages of average reduction vary from 14 to 67 percent. Pooling the data on all seven subjects results in a grand average of .379 cubic centimeters of secretion per minute during the control situation, and .226 for the hypnotic situation. This difference, .153 cc., is 7.286 times the S.D. of

TABLE II

AVERAGE SECRETION IN CC.'S PER MINUTE DURING NORMAL AND HYPNOTIC STATES, COEFFICIENTS OF CORRELATION BETWEEN RECORDS IN THE TWO STATES, CRITICAL RATIOS OF THE DIFFERENCE AND PERCENT OF AVERAGE REDUCTION OF SALIVATION DURING HYPNOSIS FOR SEVEN HYPNOTIC SUBJECTS AND TWO CONTROL SUBJECTS

S	Sex	Mean (Normal)	Mean (Hypnotic)	r	$\frac{\text{Diff.}}{\sigma \text{ diff.}}$	Percent Reduction
A	M	.475	.379	.402	1.156	20
B	M	.300	.168	.853	3.568	44
C	M	.272	.156	.860	3.625	43
D	F	.286	.247	.863	1.625	14
E	F	.703	.288	.601	4.663	67
F	F	.067	.027	.485	3.846	59
G	M	.553	.318	.789	4.052	42
Pooled data		.379	.226	.708	7.286	40
H*	M	.123	.134	.444	− .393	−8
I*	M	.392	.257	.756	2.463	34

* Control subjects

the difference, suggesting practical certainty that the two means would never overlap. The coefficient of correlation between the minute by minute records in the two situations is .708 and the average reduction in the amount of saliva secreted during the hypnotic situation is 40 percent.

As might be expected, the amount of secretion during the first minute after stimulation was usually greater than that during the second minute, and thereafter the secretion diminished gradually. Figure 1 is a graphical representation of

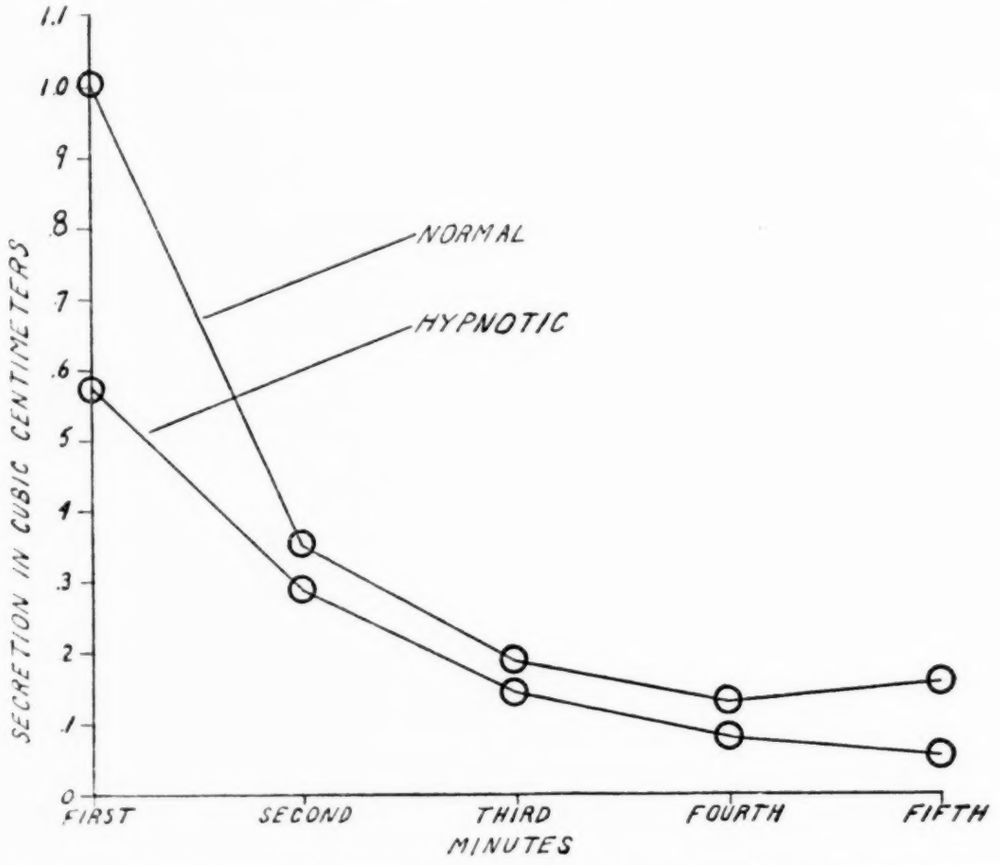

FIG. 1. Average amount of secretion per minute in the hypnotic and normal states.

the averages for the minute by minute records of the hypnotic subjects, the data for the normal and the hypnotic periods being treated separately. The diminution is obviously greater in the normal record than in that for the hypnotic state. Although the curve for the hypnotic state remains lower throughout the five-minute period, we can only speculate as to whether the curves for much longer times would be similarly related. The pronounced increase in average amount of secretion

during the fifth minute of the normal state is due to the record on one subject (E, *cf.* Table I), who in nine of twelve such cases secreted considerably more saliva during the fifth minute than during the fourth minute.

Superficial observations of the behavior of the subjects when they received the lemon juice led us to investigate the relationship between affective tone and the magnitude of the secretory response. Subjects B, C, D and F made unpleasant and seemingly involuntary facial grimaces, swallowed repeatedly, and even gasped at times, upon being stimulated. When questioned later, they reported great dislike for the juice. Subject D was so violent in her expressions of dislike during the normal state that we felt it best to ask her to inhibit them as much as she could. So far as we were able to observe, the evidence of distaste in these subjects was much less during hypnosis than in the normal periods. Subjects A, E and G reported liking the juice, or at least not disliking it. In all instances, the latter three individuals had a greater average secretion than the former ones. When we suggested to some of the hypnotized subjects that they would salivate excessively at a given signal after being dehypnotized, increased secretion occurred only in those individuals who said they liked lemon juice. Unfortunately, we know nothing of the chemical condition of the mouths of the subjects, which was probably an important factor in determining these results. That pleasantness should be related to copious secretion, and unpleasantness to diminished secretion, is perhaps to be expected. Winsor (**9**) observed a marked reduction in the amount of parotid secretion when the subject was expecting a disturbing experience, such as electric shock or distasteful food. He (**10**) suggested that such a reduction be regarded as one aspect of the general physiological pattern accompanying unpleasant emotion, rather than as a specific response by an isolated gland.

Considering the results from the hypnotic subjects only, one might be led to conclude that the effect of hypnosis is to decrease salivary secretion in response to the type of stimulation here employed. This average reduction of forty percent

in salivary secretion is in marked contrast to previous findings of little or no reduction in physiological activity during hypnosis (**8**). Although we employed no objective criterion of sleep, careful observation convinced us that the subjects were never asleep. In several instances they were asked questions at the end of the first five minute period and in all such cases they answered promptly and coherently. The hypnotic period was comparatively short and the subjects were always dehypnotized readily. The data for the two control subjects were too meager and equivocal to permit definite conclusions. Three of the four daily records for Subject H showed increased salivation during the simulation of hypnosis, though the average increase is not reliable. Subject I, whose daily records always showed diminished salivation during simulated hypnosis, had an average decrease almost as large as that for the pooled data on the seven hypnotic subjects. Of possible significance is the fact that Subject H is generally a tense, 'nervous,' active individual, who, according to his own report and to the observation of others, is unable to relax as he would like to. Subject I, a varsity basketball player, appeared to be somewhat relaxed during the simulation of hypnosis, and it should be remembered that he sometimes experienced difficulty in opening his eyes at the suggestion that he would be unable to do so. Jacobson (**4**) has recently reported that athletes generally are more successful in relaxing particular muscle groups than are ordinary student subjects. Further experimentation with non-hypnotizable subjects would of course be desirable.

The hypothesis that hypnosis itself was responsible for the decrease in salivation is reasonable if one assumes that Subject I was partially hypnotized. Perhaps a more tenable hypothesis is that general relaxation of the subjects during hypnosis (and in the case of Subject I, during simulated hypnosis) contributed to the diminution of salivation. Jacobson (**3**) has quoted Eppinger and Hess (**2**) to the effect that in vagotonia salivation is increased, leaving one to infer that relaxation would decrease the secretion. But Jacobson, during several informal discussions before psychologists, has

insisted that hypnosis hinders, rather than facilitates, relaxation. Unfortunately, we employed no criterion of relaxation in our experiments, so that we cannot resolve this seeming paradox.

Another possibility is that the verbal stimulation of the subjects during hypnosis resulted in an 'attitudinal' state, such as Winsor (**11**) has shown to be effective in reducing salivation. This seems unlikely, when one considers the infrequent and monotonous nature of the suggestions of sleep and relaxation given during hypnosis. A fourth possibility, and one which merits serious consideration, is that the threshold of response (or if one prefers, the threshold for gustatory sensation) was raised during hypnosis. This would be consistent with the fact that the subjects who found the lemon juice very unpleasant during the normal state did not object to it so much during hypnosis. It would also agree with the report of P. C. Young (**12**) that tactual sensitivity was slightly decreased during hypnosis, even though it was suggested that sensitivity would increase.

Summary

Secretion from Stenson's duct in response to stimulation of one cubic centimeter of lemon juice was measured in seven hypnotizable subjects during four periods of hypnosis and during an equal number of control periods in the normal waking state. Two persons whom we were unable to hypnotize, but who simulated hypnosis upon request, were similarly tested. The results may be summarized as follows:

1. The average secretion for the seven subjects during hypnosis was forty percent less than during the normal state. Diminution of salivation during hypnosis occurred in twenty-six of the twenty-eight experimental sessions.

2. Subjects who liked lemon juice secreted more copiously than subjects who disliked it.

3. The results in the two control subjects are equivocal.

4. Various hypotheses are suggested to account for the diminution of secretion in the hypnotized subjects and for the equivocal results in the control subjects.

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THE RELATIONSHIP BETWEEN BRAIN POTENTIALS AND PERSONALITY *

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After studying the electroencephalographic patterns of a group of individuals and finding that each person possessed a pattern peculiar to himself,[1, 2] the question arose as to whether these individuals, although having specific differences from one another, might not at the same time be classified into two or more large groups having some one or more brain wave characteristics in common.

Lemere [3] has reported that in dealing with normal subjects alone he found no correlation between extroversion or introversion and the ability or inability to produce alpha waves. Although he used no special psychological or personality tests, he states that, "most of them were questioned from a psychiatric point of view" and he "gained the impression that 'good' waves were produced in general by the cyclothymic type of individual while schizoid personalities gave 'poor' waves as a rule." The number of subjects studied was twenty-six. The alpha rhythm was classified on the basis of its amplitude, regularity, and constancy. No specific description of what 'regularity' and 'constancy' consisted is given. Apparently he differentiated between individuals with extroverted tendencies and those who were of the cyclothymic type and between those with introverted tendencies and those who were of the schizoid type. It would

* A condensation of a part of a doctor's dissertation done under the direction of Professor Lee Edward Travis.

[1] L. E. Travis and A. B. Gottlober, How consistent are an individual's brain potentials from day to day, *Science*, 1937, **85**, 223–224.

[2] L. E. Travis and A. B. Gottlober, Do brain waves have individuality, *Science* 1936, **84**, 532–533.

[3] F. Lemere, The significance of individual differences in the Berger rhythm, *Brain* 1936. **59**, 366–375.

appear that he was studying two degrees of the same trait rather than two different traits.

The present study dealt only with extremely introverted and extroverted normal individuals and therefore concerned itself with cyclothymic and schizothymic personalities.

The problem was to find what relationships, if any, existed between the percentage of time alpha waves are present in a given normal individual's record and (1) his degree of social introversion; (2) his degree of emotionality; and (3) his degree of masculinity. These three factors were measured by the Nebraska Personality Inventory.[4]

In addition to gaining an estimate of an individual's degree of introversion or extroversion by the self-rating method through use of the inventory, twenty-five of the subjects were classified as belonging primarily to one group or the other by a psychiatrist, a clinical psychologist and the writer, while the remaining forty-two were classified by only the psychologist and the writer.

Subjects

In all, sixty-seven subjects were studied, eighteen women, forty-nine men, of which the diagnosticians classified twenty-one men as introverts and twenty-eight as extroverts and seven women as introverts and eleven as extroverts. This method of classification was used as a check against that of the inventory, which indicated that while twenty-eight men rated themselves as extroverts and twenty-one as introverts, ten women rated themselves as extroverts and eight as introverts. Although the total number of introverts and extroverts as rated by self and by others agreed very closely, agreement on individual subjects amounted to 74.62 percent of the cases or fifty of the sixty-seven subjects.

Apparatus and Procedure

As in the previous studies from this laboratory, recordings were made by means of standard amplifiers and a Westinghouse oscillograph. Experimental conditions from subject to subject were kept as constant as possible. The subject reclined on a bed in a dark room. He was instructed to keep his eyes closed and his mind as free from thought as was possible. A unipolar lead placed over the left occipital area was used. The ground lead was attached to the lobe of the left ear. An average of about thirty seconds of film was recorded from each subject.

[4] J. P. Guilford and R. B. Guilford, Personality factors S, E, and M, and their measurements, *J. Psychol.*, 1936, **2**, 109–127.

Data

The data were analyzed as follows. All the waves of a record which would unequivocally fall into the classification of the alpha type (those waves with an average frequency of ten per second) were marked off. The total number of such waves was counted. A time line having a frequency of twenty-five cycles per second plus the use of a constant speed motor for rolling the film during exposure assured an exact measurement of the duration of each wave. The duration of the total record in seconds was determined and the percentage of time occupied by alpha waves was calculated. Finally, the average frequency of the alpha waves was obtained. This was an additional check for the purpose of determining whether the waves selected as being of the alpha type actually had an average frequency of eight to twelve cycles per second. The length of the record in seconds was considered to consist of those portions in which alpha or beta waves were present. Those portions during which blocking of the amplifiers occurred due to movement, etc., of the subject were not considered as part of the total duration of the record. Using percentage of time alpha waves were present as the only criterion of judgment, correlations between percentage of alpha waves present and degrees of social introversion, emotionality and masculinity were calculated.

Using the same criterion, *i.e.*, percentage of time alpha waves were present, each record was classified into one of four groups, dominant alpha, subdominant alpha, mixed alpha and rare alpha, in accordance with Davis' [5] classification.

Next it was determined what percentage of subjects diagnosed as introverts or extroverts fell into each of the four groups.

A second and grosser comparison was made. All records with alpha waves present from zero to fifty percent of the time were grouped together to make one classification, the mixed-rare and all records with alpha waves present from fifty to one hundred percent of the time were grouped together to make

[5] H. Davis and P. A. Davis, Action potentials of the brain in normal persons and in normal states, *Arch. Neurol. and Psychiat.*, 1936, **36**, 1214–1224.

another classification, the dominant-subdominant. Percentages of introverts and extroverts falling into each of these two classifications were obtained. This second category was made to determine whether tendencies for introverts and extroverts to fall into one or the other of the classifications more often might be revealed by using larger groupings if the smaller groupings failed to do so.

Finally, using only those subjects on which there was agreement of personality type between both the judges and the self-raters, calculations of percentages of extroverts and introverts falling into each of the two grosser classifications was made. The grosser method was felt to be sufficiently indicative here. Finer tendencies were already demonstrated when comparisons were made using only the judges' ratings.

Results

An analysis of the data indicates that of the subjects classified by the judges as being predominantly introverted, 42.85 percent (N = 12) fell into the dominant alpha group, 14.28 percent (N = 4) into the subdominant alpha group, 10.71 percent (N = 3) into the mixed alpha group and 32.14 percent (N = 9) into the rare alpha group. Of those subjects classified as predominantly extroverted 51.28 percent (N = 20) fell into the dominant alpha group, 30.76 percent (N = 12) into the subdominant alpha group, 7.69 percent (N = 3) into the mixed alpha group, and 10.25 percent (N = 4) into the rare alpha group.

With the grosser classifications, 57.14 percent (N = 16) of the introverts fell into the dominant-subdominant alpha group and 42.85 percent (N = 12) into the mixed-rare group. Of the extroverts, 82.05 percent (N = 32) fell into the dominant-subdominant alpha group and 17.95 percent (N = 7) into the mixed-rare group.

Both methods of classifying the data point to the same conclusions, although as was anticipated, the grosser method is the more indicative of definite tendencies.

Both the introvertive and extrovertive groups showed a greater percentage of the subjects with dominant or dominant-

subdominant alpha rhythms than with rare or mixed-rare rhythms. The difference between the dominant and the rare alpha rhythms and the dominant-subdominant and mixed-rare alpha rhythms in the case of the extroverts is a statistically true one, but this is not the case for the introverts (Tables I and II). Introverts show a greater percentage of

TABLE I

SIGNIFICANCE OF DIFFERENCES BETWEEN PERCENTAGES OF PERSONALITY TYPES FALLING INTO VARIOUS BRAIN-POTENTIAL GROUPS (DAVIS' CLASSIFICATION) AS DETERMINED BY JUDGES' RATINGS

Type (Greater Percentage Given First)	Class	Difference in Percentage of Types in Class	σ diff.	$\frac{D}{\sigma \text{ diff.}}$	Chances in 100 Diff. is True Diff. Greater than Zero
Extrovert vs. Introvert	Dominant vs. Dominant	8.43	.12	.70	76
Extrovert vs. Introvert	Subdominant vs. Subdominant	16.48	.10	1.64	96
Introvert vs. Extrovert	Mixed vs. Mixed	3.02	.07	.43	66
Introvert vs. Extrovert	Rare vs. Rare	21.89	.10	2.18	99
Introvert vs. Introvert	Dominant vs. Rare	10.71	.12	.89	82
Extrovert vs. Extrovert	Dominant vs. Rare	41.04	.09	4.56	99.99

cases with rare and mixed-rare alpha rhythms than do extroverts, with a statistically true difference. In the grosser method of classification it was found that the extroverts showed greater percentage of cases with the dominant-subdominant alpha rhythm than did the introverts and that the difference also was statistically a true one.

Considering the results obtained from the self-rating Nebraska Personality Inventory, it was found that the correlations of social-introversion (S score), emotionality (E score) and masculinity (M score) with percentage of time alpha waves are present are $-.2262 \pm .0781$, $-.0482 \pm .0822$, and $-.2102 \pm .0787$ respectively (Table III).

These low order correlations indicate that there is no relationship between self-ratings and percentage of time alpha waves are present.

When the cases on which both the judges and self-raters agreed are considered, the following is found to be true. As

TABLE II

SIGNIFICANCE OF DIFFERENCES BETWEEN PERCENTAGES OF PERSONALITY TYPES (DETERMINED BY JUDGES) FALLING INTO THE DOMINANT-SUBDOMINANT AND MIXED-RARE ALPHA CLASSES (DAVIS' CLASSIFICATION MODIFIED)

Type (Greater Percentage Given First)	Class	Difference in Percentage of Types in Class	σ diff.	$\frac{D}{\sigma \text{ diff.}}$	Chances in 100 Diff. is True Diff. Greater than Zero
Extrovert vs. Introvert	Dom.-Subdom. Dom.-Subdom.	24.91	.11	2.3	99
Introvert vs. Extrovert	Mixed-Rare Mixed-Rare	24.20	.11	2.2	99
Introvert vs. Extrovert	Dom.-Subdom. Mixed-Rare	39.19	.11	3.6	99.99
Extrovert vs. Introvert	Dom.-Subdom. Mixed-Rare	39.90	.11	3.6	99.99
Introvert vs. Introvert	Dom.-Subdom. Mixed-Rare	14.99	.132	1.14	87
Extrovert vs. Extrovert	Dom.-Subdom. Mixed-Rare	64.10	.087	7.5	99.99

TABLE III

CORRELATIONS BETWEEN NEBRASKA INVENTORY RATINGS AND PERCENTAGE OF TIME ALPHA WAVES ARE PRESENT

r alpha waves · S score $-.2262 \pm .0781$ N = 67
r alpha waves · E score $-.0483 \pm .0822$ N = 67
r alpha waves · M score $-.2102 \pm .0787$ N = 67

TABLE IV

PERCENTAGES OF INTROVERTS AND EXTROVERTS, DETERMINED BY JUDGES, FALLING INTO THE TWO CATEGORIES OF THE MODIFIED DAVIS CLASSIFICATION

Type	Class	N	Percentage of Type in Class
Introvert	Dom.-Subdom.	16	65.00
Introvert	Mixed-Rare	12	35.00
Extrovert	Dom.-Subdom.	32	83.33
Extrovert	Mixed-Rare	7	16.66

in the calculations based on the judges' ratings alone, extroverts showed the dominant-subdominant alpha rhythm more often than the mixed-rare and this difference was statistically significant (Table V). All other differences found were not statistically true ones.

TABLE V

SIGNIFICANCE OF DIFFERENCES BETWEEN PERCENTAGES OF PERSONALITY TYPES FALLING INTO THE DOMINANT-SUBDOMINANT AND MIXED-RARE ALPHA CLASSES (DAVIS' CLASSIFICATION MODIFIED) OF CASES WHERE RATINGS BY JUDGES AND SELF-RATERS AGREED (BASED ON TABLE IV)

Type (Greater Percentage Given First)	Class	Difference in Percentage of Types in Class	σ diff.	$\frac{D}{\sigma \text{ diff.}}$	Chances in 100 Diff. is True Diff. Greater than Zero
Extrovert vs. Introvert	Dom.-Subdom. vs. Dom.-Subdom.	18.33	.12	1.52	93
Introvert vs. Extrovert	Mixed-Rare vs. Mixed-Rare	18.34	.12	1.52	93
Introvert vs. Extrovert	Dom.-Subdom. vs. Mixed-Rare	48.34	.12	4.02	99.99
Extrovert vs. Introvert	Dom.-Subdom. vs. Mixed-Rare	48.33	.12	4.02	99.99
Introvert vs. Introvert	Dom.-Subdom. vs. Mixed-Rare	30.00	.15	2.00	98
Extrovert vs. Extrovert	Dom.-Subdom. vs. Mixed-Rare	66.67	.09	7.63	99.99

It is to be observed that these results do not agree with Lemere's findings either with his introverts and extroverts or cyclothymes and schizothymes. The explanation for this may rest in the fact that his cases were fewer in number and his methods of classification of types different. In addition, his criteria for designating alpha waves as 'good' or 'poor' and the criteria used in this study for classifying records into dominant-subdominant or mixed-rare groups are not exactly comparable.

CONCLUSIONS

From these findings it may be concluded that a majority of the normal individuals exhibiting a high degree of extroversion will show a dominant-subdominant alpha rhythm.

It cannot yet be stated that introverts will show a predominantly mixed-rare rhythm.

Remembering always that the electroencephalogram is a manifestation of a fundamentally neurophysiological phenomenon, it seems not unreasonable to believe that its characteristic nature is neither a cause nor a result of the subject's degree of extroversion or introversion but rather that both are concomitants in an organismic whole. It is suggested only that an organismic pattern in which a dominant-subdominant rhythm appears accompanied by an extroverted personality as determined by our methods of rating, will be more common than one in which it appears accompanied by an introverted personality. In the light of the present evidence, no other definite statement can be made.

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AN EXPERIMENTAL STUDY OF THE REACTION TIME OF THE CEREBRAL HEMISPHERES IN RELATION TO HANDEDNESS AND EYEDNESS

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The Problem

The purpose of the present study was first, to see if the alleged hemispheral dominance can be expressed in terms of reaction time, and second, to determine the relationship between brainedness, handedness, and eyedness on the basis of reaction time. To satisfy the conditions of the problem it is obviously necessary to stimulate the hemispheres independently. The key to such an investigation lies in the unique distribution of nerve fibers from the two retinas to the cerebral hemispheres. All the fibers from the temporal half of the right retina are represented in the occipital lobe of the right cerebral hemisphere while those from the nasal half are represented in the occipital lobe of the left hemisphere. Likewise the fibers from the temporal and nasal halves of the left retina are represented in the left and right hemispheres respectively. Thus all the fibers from the temporal half of each retina are represented in the corresponding hemispheres, while all those from the nasal halves cross over and are represented in the opposite hemispheres (**2**).

It would thus appear that when a beam of light coming from a source in the left field of vision stimulates a point in the temporal half of the right retina, or the nasal half of the left retina, the nerve impulses originating at those points must be transmitted to the visual center in the right hemisphere.

Obviously, a large difference between the reaction times resulting from the stimulation of the temporal and nasal halves of the two retinas must mean either a corresponding

difference in the sensitivity of the two halves of the retinas or a corresponding difference between the reaction times of the two hemispheres, or possibly both. Although it is conceivable and probable that the sensitivity of one retina differs appreciably from that of the other, and also that a given area in either retina may be, and perhaps is, more or less sensitive than another area in the same retina, it is nevertheless highly improbable that four corresponding areas in the temporal and nasal halves of the two retinas will show any appreciable ultimate difference. Suppose, for example that the temporal half of each retina is more sensitive than the nasal half. Since the nasal half of each retina is represented in the opposite hemisphere, any difference between the sensitivity of the two halves of each retina will be cancelled out by stimulating both the nasal and temporal halves of both retinas.

The Experiment

In our experimental procedure, in order to control the optical angle, the lenses were removed from a stereoscope and the front portion, or card carrying arm, was sawed off leaving only the hood and handle. Discs of black card board were inserted in place of the lenses. A small hole was punched in one disc, the other being opaque. The observer held this remodelled stereoscope before his eyes and fixated a spot of light directly in front. To make sure that the stimulus did not fall upon the optical disc (blind spot), the optical angle was made large enough to allow the stimuli on the nasal halves to fall more than 3 mm from the macula lutae.

The observer was told that a light in his right (or left) visual field would be flashed on and that, as soon as he saw the light through the small hole in the artificial lense, he must press the key. The reaction time was measured by means of a Hipp chronoscope which was operated by electromagnets; the experimenter's key started the clock and switched on the light synchronously, while the observer's key stopped the clock.

One hundred reactions were taken for each of the four positions, *i.e.*, the temporal and nasal halves of each retina,

and for both the right and left hand, on twelve observers, or a total of 9600 separate reactions. For the purpose of comparison the reaction time for direct vision was also obtained, making 2400 additional reactions, or a total of 12,000, reactions. Each trial was preceded by a short practice period of about 25 reactions. Only one trial of 100 reactions was made at one sitting. A short rest period was also provided in the middle of every trial. The experiments were made in the afternoon in a semidarkened room.

We were concerned first of all to know whether, under these conditions, our measurements of reaction time are reliable. For this purpose, we computed the standard deviations of the reaction time for each trial for each of the twelve observers, for direct and indirect stimulation and for both right and left hands, or a total of 24 standard deviations.

The average of the means of the 12 trials on direct stimulation was found to be .199 for the right hand and .197 for the left hand. The standard deviations were .022 and .020 respectively. Thus it is seen that the average mean for both hands is .198 and the standard deviation is .021. The average of the limits for both hands is .70 and .337.

On indirect stimulation the average of all the means of the 96 trials was found to be .249 and the standard deviation was .026. These results are shown graphically in the accompanying curve (Fig. 1).

To test further the reliability of the measurements, a correlation was obtained between the first and second half of each trial in a sampling of 36 trials, three for each of the twelve observers. This procedure yielded a correlation of 0.82.

Results

Reaction Time of the Hemispheres

Table I presents a comparison between central, or foveal stimulation, and peripheral (Temporal and nasal) stimulation. It will be seen that the reaction time is shorter for foveal than for either temporal or nasal stimulation; and also, it is shorter for stimulation of the nasal than of the temporal half of each retina.

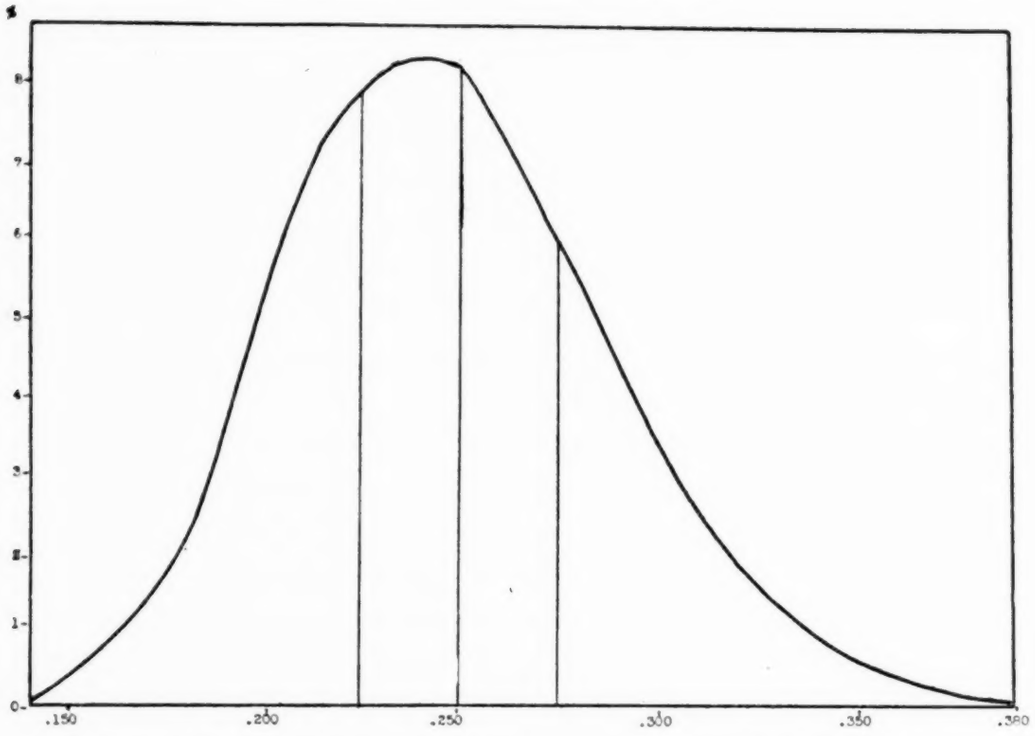

FIG. 1. The abscissa represents the reaction times in thousandths of a second; the ordinant the frequency in percentages. The vertical lines represent the average and standard deviations, .249 and ± .026 respectively. The number of reaction times included in the distribution was 9600.

These results are not in accord with Travis's study on retinal summation which showed the temporal half of the retina to be apparently more sensitive than the nasal half (3). However, Travis was measuring acuity of vision, while the present study is concerned with reaction time which unmistakably involves motor activities in the hemisphere.

Thus, referring to our early statement that all the fibers

TABLE I

	Right Eye	Left Eye	Ave. Both Eyes
Temp.	.258	.257	.2575
Direct	.198	.198	.198
	.060	.059	.0595
Nasal	.248	.236	.242
Direct	.198	.198	.198
	.050	.038	.044
Temp.	.258	.257	.2575
Nasal	.248	.236	.242
	.010	.021	.0155

from the temporal half of each retina are represented in the corresponding hemisphere and that all those from the nasal half are represented in the opposite hemisphere, it follows that stimulation of the temporal half of the right eye and the nasal half of the left eye elicits reactions of the right hemisphere, and likewise stimulation of the temporal half of the left eye and the nasal half of the right produces reactions of the left hemisphere. Hence if we take the average of the reactions to the two sources of stimulation, we should be able to compare the reaction times of the two hemispheres directly on the basis of indirect stimulation of the nasal and temporal halves of both eyes.

Assuming that we have measured the reaction times of the two hemispheres by this method, and if we take the average of the twelve observers, the results show no significant difference between the reaction times of the right and left hemispheres (see Table II). It will be observed that the

TABLE II

	Right Hand				Left Hand			
	R. Hem.	L. Hem.	R. Sup.	L. Sup.	R. Hem.	L. Hem.	R. Sup.	L. Sup.
A	237	294	.021		.284	.299	.015	
B	258	280	.022		.256	.253		.003
C	240	252	.012		.231	.257	.026	
D	248	253	.005		.239	.246	.007	
E	241	229		.012	.239	.236		.003
F	244	244	.000	.000	.261	.252		.009
G	236	236	.000	.000	.235	.229		.006
H	290	291	.001		.270	.285	.015	
I	247	242		.005	.253	.243		.010
J	212	223	.012		.210	.232	.022	
K	242	224		.018	.277	.251		.026
L	241	241	.000	.000	.235	.251	.016	
Ave.	248	251	.012	.012	.248	.252	.017	.009

reaction times of the right and left hemispheres for the right hand are .248 and .251 respectively, or a difference of 3 sigma; and that the reaction times of the two hemispheres for the left hand are .248 and .252 respectively; or a difference of 4 sigma. It also appears from these results that there is virtually no difference between the reaction times of the right

and left hand either for indirect vision or for direct vision when the average of all observers is taken.

If, however, we take the individuals, there are six with an average difference of 13 sigma in favor of the right hemisphere and six with an average difference of 16 sigma in favor of the left hemisphere.

Or, if we consider the individuals with reference to the reaction times of the right and left hands respectively, we observe that six observers give an average difference of 12 sigma for the right hand in favor of the right hemisphere and that three observers give an average difference of 12 sigma for the right hand in favor of the left hemisphere, while three give no difference in favor of either hemisphere. For the left hand, six observers give an average difference of 17 sigma in favor of the right hemisphere and six give an average of 9 sigma in favor of the left hemisphere.

Since the left hemisphere is supposed to control the movements of the right hand and the right hemisphere those of the left hand, it would seem to follow that the reaction time of the right hand should be shorter with stimulation of the left hemisphere than with stimulation of the right hemisphere; also that the reaction time of the left hand should be shorter with stimulation of the right hemisphere than with that of the left. The facts however, do not support this presumption in more than half of the cases. Thus it appears from the results of this study that hemispheral superiority in so far as it concerns reaction time is a matter of individual differences with the dice weight slightly in favor of the right hemisphere. A larger number of observers might easily turn the balance in the other direction.

Although all but one of the observers was right handed, the use of the right hand in general seems to have had no effect on a simple movement such as pressing a reaction key. It was found, however, that in a tapping test, a large majority of the right-handed observers tapped more rapidly with the right than with the left hand. The difference between the two types of reaction time can undoubtedly be explained by the greater complexity and coördination involved in tapping than in simply pressing a key.

Eyedness in Relation to Handedness and Brainedness

One further question was investigated, namely, is eyedness in any way related to handedness and brainedness in terms of reaction time? A considerable amount of theoretical discussion and experimental data have been produced during the last two decades on the genetic relationship between brainedness, handedness, and eyedness. Regarding the anatomical basis of brainedness, and handedness, Fischer (1) comments as follows: "We know that right-handedness is the rule among human beings. Still, right-handedness gives another indication of the immense difficulties that assail us when we strive to distinguish between hereditary foundations and parakinetic influences. Nothing is really known about the origination of right-handedness or left-handedness. Unquestionably, however, in many individuals there must be an anatomical basis for the preference given to one hand or the other. This is shown beyond question by the fact that so many left-handed persons remain left-handed in defiance of the most strenuous attempts to educate them to right-handedness."

L. E. Travis in his *Speech Pathology* quotes extensively from investigations and theoretical discussions of the question of the origin of hemispheral dominance, hand dominance, and eye dominance. For example, Parsons, "in a test of 877 public school children found 29.3 percent of them to be left-eyed. Of the 608 right-eyed children 99.5 percent were right-handed. But of the 257 left-eyed children only 12.4 percent were found to be left-handed" (4). Other workers quoted by Travis, report less correspondence between right-handedness and right-eyedness than does Parsons, but all studies show a high, though not a perfect, correlation between eyedness and handedness.

The present study is concerned with the reaction time of the two hemispheres in relation to right and left-eyedness. Of the eight observers who are right-eyed, three showed superiority of the right hemisphere with an average difference of 13 sigma, while five showed superiority of the left hemisphere with an average difference of 8 sigma. We see here a wide

divergence between right-eyed and left-eyed observers with respect to the reaction time of the two hemispheres. The same sort of divergence appears when we take the reaction times of the right and left hands separately.

A follow up study of eye dominance was made in an experiment on speed of tapping. Seventy-four students in general psychology were tested for speed of tapping with the right and left hands respectively. Ten trials of five seconds each were taken with each hand. Correlations were obtained between the speed of tapping (number of taps per 5 second periods) for the right and left hands. Taking the group without reference to eye dominance, a correlation of 0.66 was obtained. The fifty-two observers who were right-handed and right-eyed, yielded a correlation of 0.78, while the twenty-two who were right-handed but left-eyed, yielded a correlation of 0.34. No correlation was obtained for left-handed observers.

Conclusion

In considering the results of this study it is necessary to distinguish between 'dominance' and 'superiority' with reference to brainedness, eyedness and handedness. Dominance means simply preference for one hemisphere, eye or hand rather than the other. According to this view of dominance our movements are directed predominantly by one hemisphere —the left hemisphere in right-handed people and the right hemisphere in left-handed people. So also, the use of the right or left hand and of the right or left eye is a matter of preference. Superiority, on the other hand, refers to greater efficiency, *i.e.*, shorter reaction time of one hemisphere or hand, or eye, than of the opposite.

The results reveal no uniform superiority of either hemisphere, and no significant difference between the reaction times of the two hands in a simple reaction experiment when the average of all the reactions is taken.

When, however, the reactions of the separate individuals are compared it is found that individuals differ somewhat widely with reference to hemispheral and hand superiority, being divided approximately equally between superiority of

the right and left hemispheres regardless of whether they are right or left handed. The results, therefore, give support to the conclusion that the cerebral hemispheres act together as a unit and that superiority of either one is probably due to certain anatomical and environmental factors determining variability. What precisely these factors are is a matter of conjecture.

Eyedness seems to be definitely correlated with handedness and brainedness as regards reaction time.

(Manuscript received July 27, 1937)

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STUDIES IN THERMAL SENSITIVITY: 2. ADAPTATION WITH A SERIES OF SMALL RECTANGULAR STIMULATORS

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In the preceding investigation,[1] adaptation phenomena were studied with a set of small circular stimulators. Among the four subjects, the length of time for complete adaptation appeared to be variously related to either or both of two factors: (1) initial strength of sensation, in itself roughly proportional to the square root of the stimulator area; (2) some dimension of the stimulator as such—probably the perimeter. (For the sake of brevity, these two factors will hereafter be referred to as the *initial strength effect* and the *perimeter effect.* This does not necessarily imply any causal relationship.) With circular stimulators, the square root of the area and the perimeter are covariant; so that the separation of the two effects had to be based upon introspective reports of strength of sensation. With rectangular stimulators, square root of area and perimeter can be varied independently, thus providing a direct objective check.

Apparatus and Procedure

From the numerous possibilities, the following set of rectangular stimulators was adopted: Each stimulator was made 10 mm long and equal in area to the correspondingly-numbered circular stimulator. A neutral field disc was constructed with slides so that the rectangular opening could be adjusted to the size of the stimulator. The important dimensions of this set of stimulators are shown in Table I. A No. 10 stimulator could not be used because of limitations in the stimulating apparatus. A No. 8 stimulator was omitted from the series as a matter of economy in running time.

The procedure was the same as that used in the circular series and the same four subjects were employed. Data were taken in February, March and April, 1937—thus overlapping with the latter part of the earlier study. Approximately six sets of eight individual readings were run with each size of stimulator—half with the stimulator placed longitudinally and half with it at right angles to the line joining wrist and elbow.

[1] Jenkins, W. L. Studies in thermal sensitivity: 1. Adaptation with a series of small circular stimulators. *J. Exper. Psychol.*, 21: 670–677, No. 6, December, 1937.

TABLE I

DIMENSIONS OF RECTANGULAR STIMULATORS

Stim. No.	Length mm	Width mm	Area sq. mm	Perim. mm	Equivalent to Circ. Stim.	
					in Area	in Perim.
1	10	.121	1.21	20.2	No. 1	Nos. 6–7
2	10	.314	3.14	20.6	No. 2	Nos. 6–7
3	10	.716	7.16	21.4	No. 3	Nos. 6–7
4	10	1.260	12.60	22.5	No. 4	No. 7
5	10	1.965	19.65	23.9	No. 5	Nos. 7–8
6	10	2.83	28.30	25.7	No. 6	No. 8
7	10	3.86	38.60	27.7	No. 7	Nos. 8–9
9	10	6.45	64.50	32.9	No. 9	No. 10+

RESULTS

The two most critical cases will be considered first. On the basis of the circular series, Sc-44° showed practically a pure initial strength effect and De-10° practically a pure perimeter effect. With rectangular stimulators, *Sc-44° should show no change* in the level of median adaptation times and the curve should interweave with that for circular stimulators. On the other hand, *De-10° should show a marked upward shift*, especially in the smaller sizes where the change in perimeter is greatest. For a perfect case, adaptation times should be proportional only to perimeter and totally independent of the area.

Sc-44° (Fig. 1) clearly meets the critical test. The rectangular and circular curves intertwine, three rectangular values being higher, three lower and two equal to the corresponding circular values. Further confirmation is found in the analysis according to subjective report. In the right-hand chart, we find three well-separated, almost-horizontal lines at nearly the identical levels of the corresponding curves in the circular chart. The individual readings, moreover, show the same high consistency that was observed with circular stimulators. When arranged in descending order, all the strong adaptation times come first, then all the medium and then all the weak—with very little overlapping.

De-10° (Fig. 3) passes the critical test equally well. The rectangular medians lie definitely above those for circular

stimulators throughout the curves. More than that, the rectangular medians actually meet the criterion for a perfect case, as is clearly shown by the right-hand chart. Median

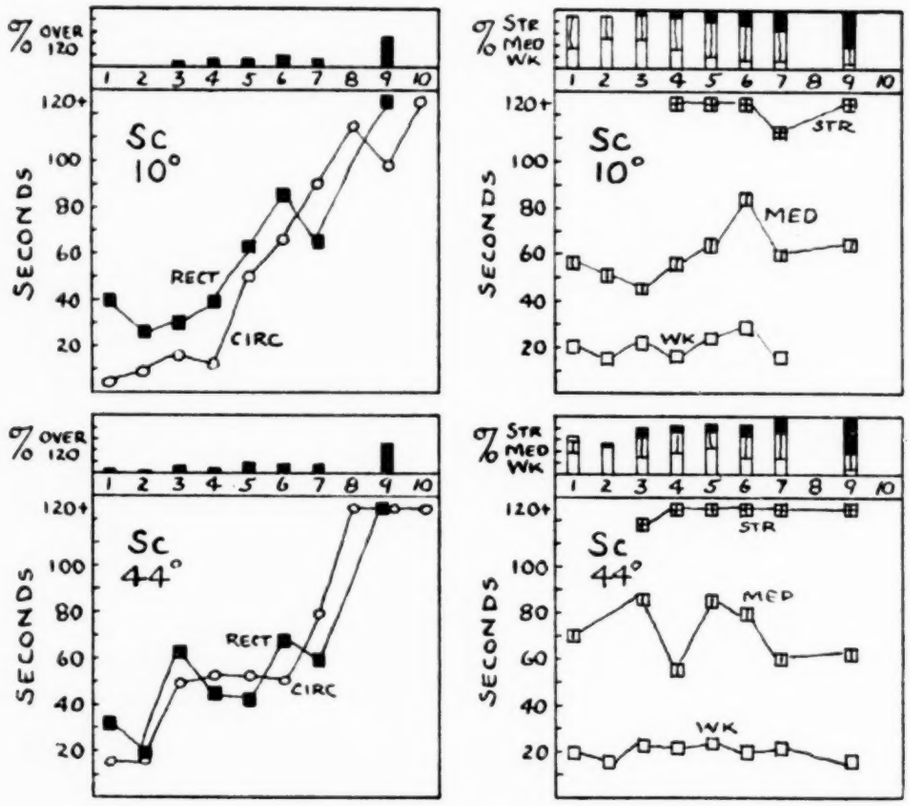


FIG. 1.

adaptation time is proportional to perimeter and independent of the area of the stimulator. In this subject, adaptation time was also measured with a special 13 mm circular stimulator (perimeter 40.8); this lies on the same curve with the other values.

If further confirmation is needed, it is provided by Al-10° (Fig. 2) where the larger absolute values make the shift with rectangular stimulators appear more striking. Again, when the median adaptation times are plotted against perimeter, the same sort of relation is apparent. The perimeter effect is clearly the major influence.

Results in the other cases need be reviewed but briefly. Sc-10° (Fig. 1) shows a major initial strength effect and a minor perimeter effect. Al-44° (Fig. 2) and De-44° (Fig. 3) both show a major perimeter effect, which appears to be

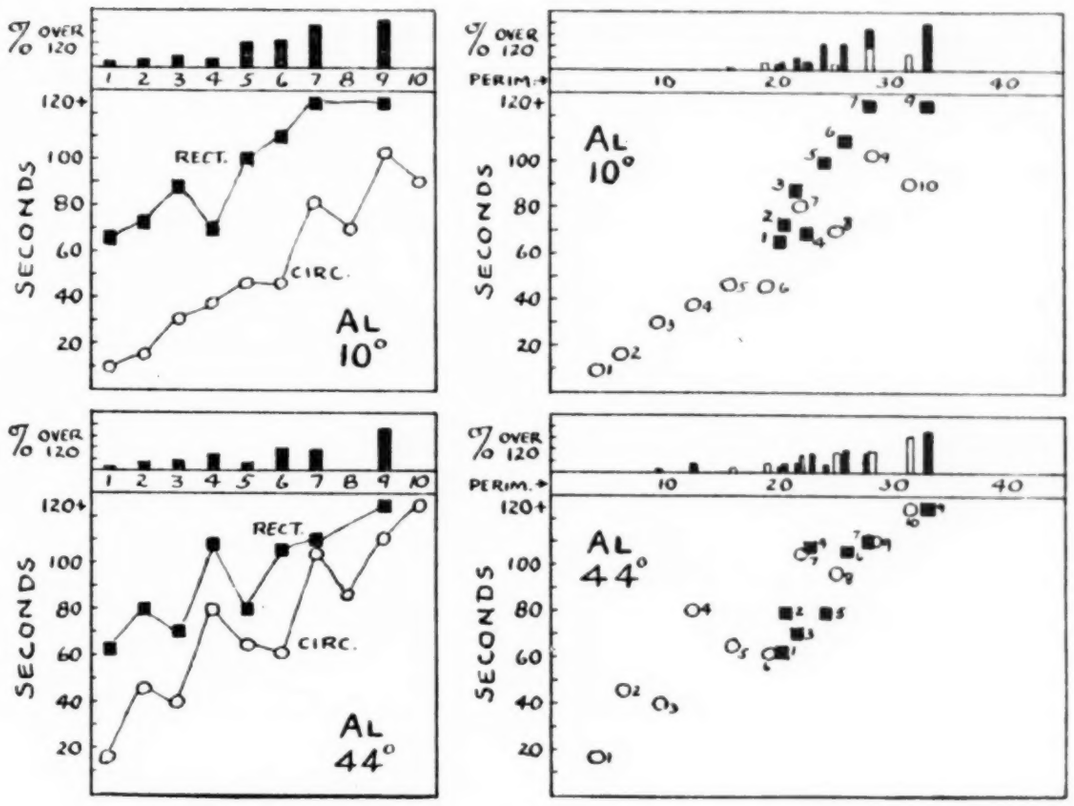

% OVER 120
1 2 3 4 5 6 7 8 9 10
120+
100
80
60
40
20
SECONDS
RECT.
CIRC.
AL 10°
PERIM.→
10 20 30 40
AL 44°

FIG. 2.

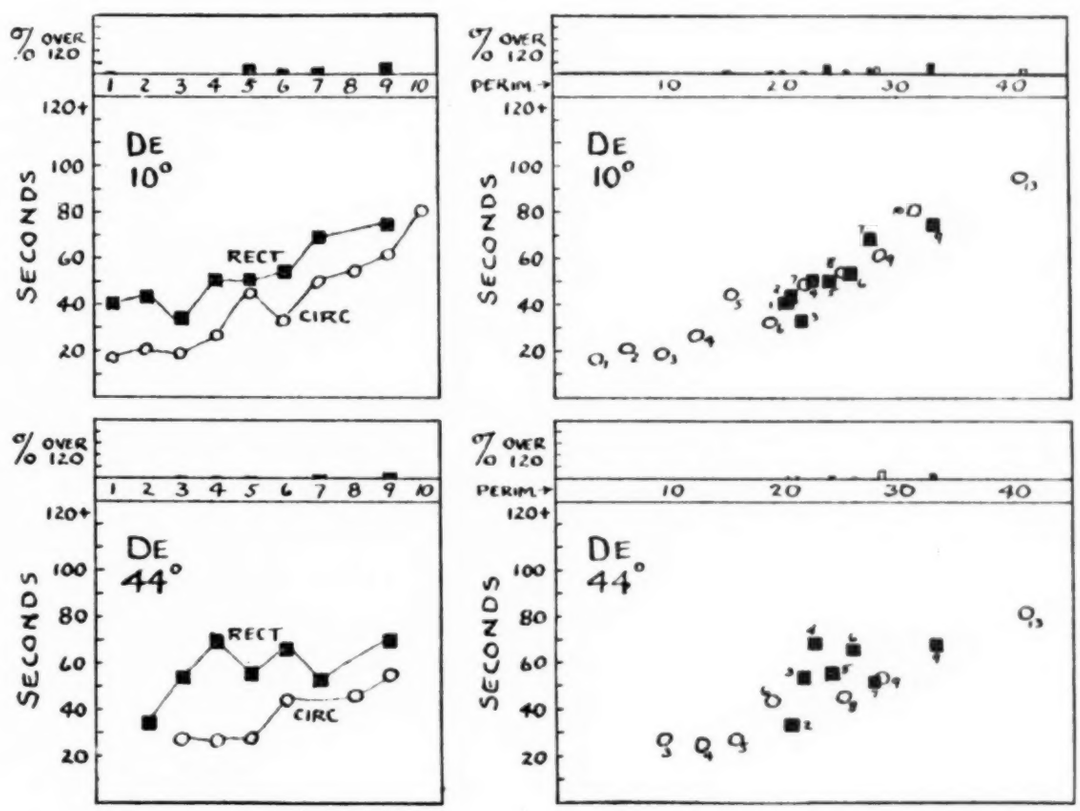

% OVER 120
1 2 3 4 5 6 7 8 9 10
120+
100
80
60
40
20
SECONDS
RECT.
CIRC
DE 10°
PERIM.→
10 20 30 40
DE 44°

FIG. 3.

somewhat less than that with 10°. Sm-10° (Fig. 4) shows no evidence of a perimeter effect, since the two curves interweave, and all values are at a very low level. Concerning Sm-44° we can still draw no conclusions, because of the extremely

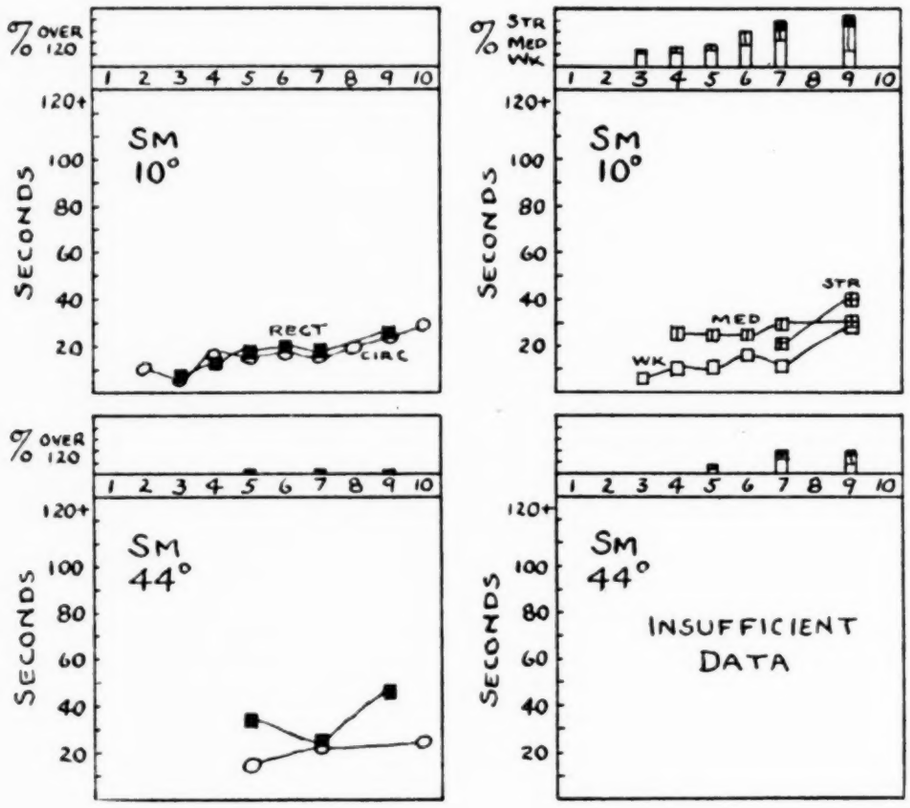


FIG. 4.

poor response to stimulation. It would seem, then, that all the postulates concerning these subjects are confirmed by the rectangular data.

As a minor contribution, we may note that there is a definite sign of a *configurational effect*, which is evidenced by (*a*) an increase in the percentage of response to stimulation; (*b*) an increase in the percentage of strong and medium sensations experienced—most marked with the smaller sizes. Whether this is purely a central perceptual effect, or whether a thin rectangle actually touches upon more receptors than a small round dot, the present evidence cannot decide.

Summary

Adaptation phenomena with a series of rectangular stimulators, equivalent in area but varying in perimeter as compared with the earlier series of circular stimulators, are here reported for the same four subjects. In every instance, the postulates based on the circular series are confirmed. Where the subject showed a pure initial strength effect with circular stimulators, the wide changes in perimeters do not affect the adaptation time values. Where the subject showed a pure or practically pure perimeter effect, adaptation time remains solely proportional to perimeter, regardless of area or form. The separation of an *initial strength effect* and a *perimeter effect* in relation to adaptation time is thus objectively confirmed. As a minor contribution, a *configurational effect* upon percentage of response and strength of sensation is noted.

(Manuscript received July 13, 1937)

STAMMERING AND LEFT-HANDEDNESS: A GRAPHIC STUDY

BY CLARENCE QUINAN

In an earlier study [1] quantitative graphic time measurements were made with a group of four university men—two dextrals and two sinistrals. This work was done with a stop-watch once daily on 25 experiment days, the performances of each reactor being determined while he wrote with each hand a model sentence dextrad and also sinistrad. On tabulating these time data suitably it was found: 1, without exception that each column of figures exhibited a remarkable process of involuntary, progressive time acceleration; 2, that the two mirror-writing time values noted as to each person tested displayed as it were a sort of kinetic isomorphism since, as to the dextrals, such paired values always diminished from left to right while just the opposite of this finding obtained as regarded those of the left-handers. Hence simply by paying attention to this peculiarity of the mirror-writing data, one could make out the brainedness type in any given instance—right or left as the case might be. Perhaps I should add that a so-called 'change of handedness' did not in the least modify the brainedness factor.

Having met with a family group which offered a problem in regard to a factor which, it would seem, perhaps may be referred to as one of kinetic heredity, the present research was entered upon with a two-fold purpose in view. Primarily it was desired to classify this family in terms of brainedness types—left or right—but also additional data were needed as to the phenomenon already mentioned—*i.e.*, the acceleration of the handwriting velocity factor.

This article describes therefore the three sets of graphic data secured on 16 experiment days from a left-handed girl

[1] Quinan, C.: Can the brainedness factor right or left be established by graphic time data alone?, *J. Exper. Psychol.*, 21: 230–235, No. 2, August, 1937.

six years of age, and from her dextral parents. As regarded the parents the usual test sentence was employed as the model upon which to base the time measurements; in the case of the child, however, since she had had no training whatever in penmanship, a single word was used in place of the sentence. This word she printed.

On scrutinizing the sets of speed data obtained respectively from the members of this group it became obvious at once: 1, that the child was definitely, though erratically, right-brained; 2, that her parents were left-brained; 3, that the acceleration process manifested itself characteristically.

Although this contribution presents but 96 mirror-writing time values, nevertheless, it was considered worth while to put them forward, since it seems probable that kinetic data such as these may be found useful in connection with the study of laterality problems.

It will be convenient to consider in turn: 1, the child's family history; 2, her physique and personality; 3, the method of study pursued; 4, the experimental results.

TABLE I

DATA IN REGARD TO EYEDNESS AND HANDEDNESS

	Father	Mother	Child
Which eye is dominant?	Right	Left	Left
Which hand:			
1. Throws a ball?	Right	Right	Left
2. Holds bread knife?	"	"	"
3. Brushes teeth?	"	"	"
4. Deals out cards?	"	"	"
5. Holds needle?	"	"	"
6. Holds cup?	"	"	"
7. Holds scissors?	"	"	"
8. Peels potatoes?	"	"	"
9. Holds hammer?	"	"	"

FAMILY HISTORY

Vigorous and in the enjoyment of excellent health, the girl's parents appear to be relatively normal persons; both are descendants of old American families. The mother is a public health nurse, detailed for duty at a high school. The father is a skilled mechanic. She sang formerly; he plays the violin.

As regards left-handedness, on the father's side the family history is negative. On the mother's side, however, one uncle (maternal) was a left-hander.

Respecting speech disorders the mother states that she herself stammered now and again as a child; that one of her aunts (maternal) and one of her uncles (paternal) also suffered with this affliction. There was no instance of stammering in the father's family. As for the child, save for occasional inarticulate repetition-movements on the part of her lips, her speech mechanism appeared to be normal. However, I was told that on a number of occasions she had gone through episodes of severe stammering.

The individual reactions of this little family group in regard to the fixed factor of 'eyedness' and to the relatively variable factor of 'handedness' are set forth in Table I.

Physique and Personality

As regards her figure, the child is symmetrically built; also her standing posture is erect and she carries herself well. With respect to her physical type she is, however, rather slender. Her features are decidedly attractive, somewhat delicate. A cursory physical survey brought to light little of significance with the exception of a marked tactile hemi-hyperæsthesia.

Often about the child's eyes, the pupils of which are large, one could recognize a mischievous, quizzical expression. This may be associated with the gift she seems to possess in the line of mimicry—a gift at which she is said to be quite clever. She is extremely restless and excitable. For example, in anticipation of some little indulgence or other, or under the influence of any exciting circumstance, she has a habit of clenching her fists and then, with rigid muscles, imparts a sort of quivering movement or vibration to her extended arms. She is very timid. Thus although from her bedroom she can distinctly hear the voices of her parents, often before going to sleep she whimpers with fear, must be soothed. Also her tendency to laugh immoderately on slight provocation seems to indicate that she is emotionally unstable.

She shows good judgement in the use of colors and displays some skill in the work of applying them on a design.

Music evidently appeals to her. For example, if a composition being rendered over the radio happens to please her, she reacts to it by hovering about the instrument and singing softly to herself. She herself plays the violin—rather well, so her parents say. But she plays it for them alone. Indeed she cannot be induced to play for others—not even for her grandparents. She did let me see her instrument—not, however, without much hesitation. Of dress she is excessively fond—perhaps somewhat more so than the average little girl of her age.

She does well with her lessons; and although no IQ data were available, she appeared to be of at least average intelligence.

Method

The technic has been described in detail elsewhere.[2] In each instance the time measurements were made once daily. The parents were timed on this sentence: "He protested that he couldn't eat the twenty-two tarts; and the truth is that he ate twenty." In the case of the child the model word used was 'Lender.' This word was set before her in large, block capital letters. It occurred to me later that the word 'Leerer' would have been a still better one to use. Having never before tried to write with a pen, the child often failed to hold it in a suitable writing-position and thus lost time in trying to get the ink to flow properly. Her chirographic efforts were limited of course to straight lines, dabbed with an unsteady hand on the writing material. The test word 'Lender' was selected for two reasons—first because it can be printed with 18 strokes 15 of which are straight, second, because with it the problem of text reversal—*i.e.*, mirror-writing—can be accomplished largely by means of straight lines.

Each reactor was urged to write with all possible speed.

[2] *Op. cit.*

TABLE II

QUANTITATIVE GRAPHIC TIME DATA OBTAINED RESPECTIVELY FROM TWO DEXTRAL ADULTS AND FROM THEIR LEFT-HANDED DAUGHTER, AGED SIX YEARS

The three sets of figures shown exhibit alike an involuntary acceleration of the time factor. Likewise isomorphic forms of this kinetic phenomenon are clearly shown, the time data of each parent being of the left type, those of the child being of the right or mirrored-type.

Test Day No.	Mirror-Writing Time Values in Seconds					
	Mother		Father		Child	
	Hand:		Hand:		Hand:	
	L	R	L	R	L	R
1	220	290	160	180	62	115
2	168	207	130	126	35	59
3	114	110	100	101	35	67
4	109	92	86	76	53	33
5	99	82	79	76	28	35
6	97	77	62	61	25	29
7	82	67	65	57	25	25
8	72	62	55	54	23	25
9	70	60	58	52	19	16
10	60	52	55	51	15	19
11	56	50	49	42	13	13
12	51	47	57	41	12	12
13	50	46	41	39	17	19
14	48	43	42	38	17	19
15	53	43	39	36	17	17
16	46	40	35	29	14	14

Note: The time values of the parents refer to a model sentence, those of the child, to the model word 'LENDER.' This word she printed.

RESULTS

Since the experimental findings set forth in Table II duplicate almost exactly those described in the opening paragraph of this article, it follows: 1, that the father and the mother, alike, are left-brained—*i.e.*, their graphic time data exhibit left kinetic isomorphism; 2, that the little girl is right-brained—her graphic values display right kinetic isomorphism. And since the respective sets of time data obtained from members of this family show in each instance a phenomenon of time acceleration, these experimental results may be said to answer fully the objectives set up at the outset of this research.

However, I should like now to invite attention for a moment to another peculiarity of the graphic time data—one which has to do with what seems to be a critical period.

Appearing, if at all, only at the outset of a series of timed writing experiments, this critical period may extend over four days. Thus on referring to the mother's record (Table II) it will be observed that a curious change occurred on the third day. For on that day, it will be noted, the factor of kinetic leadership passed suddenly from the left hand (right hemisphere) to the right hand (left hemisphere). In the father's case a similar change occurred albeit more gradually—it did not establish itself clearly until the fourth day. The data referable to the child, it will be observed, fail to exhibit this phenomenon—undoubtedly the discrepancy to be noted as to the fourth day was due to fumbling. It should be understood that a critical period is not encountered in every case. Seemingly this manifestation occurs only in dextrals; at any rate none of the sinistrals from whom I have secured suitable data—six persons in all—exhibited any such peculiarity.

A few remarks should be added here in regard to one other point. Respecting the time results turned off by the child it will be noted that while they were predominantly of the right isomorphic type yet at the same time they were also somewhat erratic. Indeed on five occasions they agreed with one another exactly.

Now this state of equality as to the time data seemed to fit in perfectly with the child's manual peculiarities. For although she undoubtedly has a natural tendency to favor the left hand, nevertheless, it was impossible to detect the slightest difference in regard to the readiness with which she wrote—either dextrad or sinistrad—now with one hand now with the other. Apparently with equal freedom of movement she wrote mirror-wise as easily with her right hand as she did with her left hand. Only twice—with each hand—did she fail to reverse properly the letter R. Since she is excessively timid and since, as the time data show, not rarely the values noted as to her reversed writings were precisely equivalent, the idea suggested itself that perhaps the fear emotion—

possibly, also, a tendency to stammer—may be attributable in some degree to the existence, momentarily, of a dead-center situation wherein the person concerned wavers uncertainly, being unable for a time to move decisively either dextrad or sinistrad.

Summary

1. Graphic experiments are described referable to a family of three persons—the dextral parents and a left-handed girl, six years of age, who is prone to stammer.

2. In each instance the time data obtained exhibited a curious phenomenon of progressive acceleration.

3. The quantitative graphic time data obtained, in seconds, showed clearly: 1, that the parents were left-brained; 2, that the child was right-brained.

4. As regarded the two dextrals, an initial critical period covering four days was noted wherein the factor of kinetic leadership passed quite abruptly from the right hemisphere to the left hemisphere. This appears to be a dextral peculiarity.

5. Considerations are advanced in regard to a kinetic relationship supposed to exist between a dead-center principle and the speech disorder called stammering.

(Manuscript received August 10, 1937)

A SUGGESTED IMPROVEMENT IN VOICE KEY CONSTRUCTION

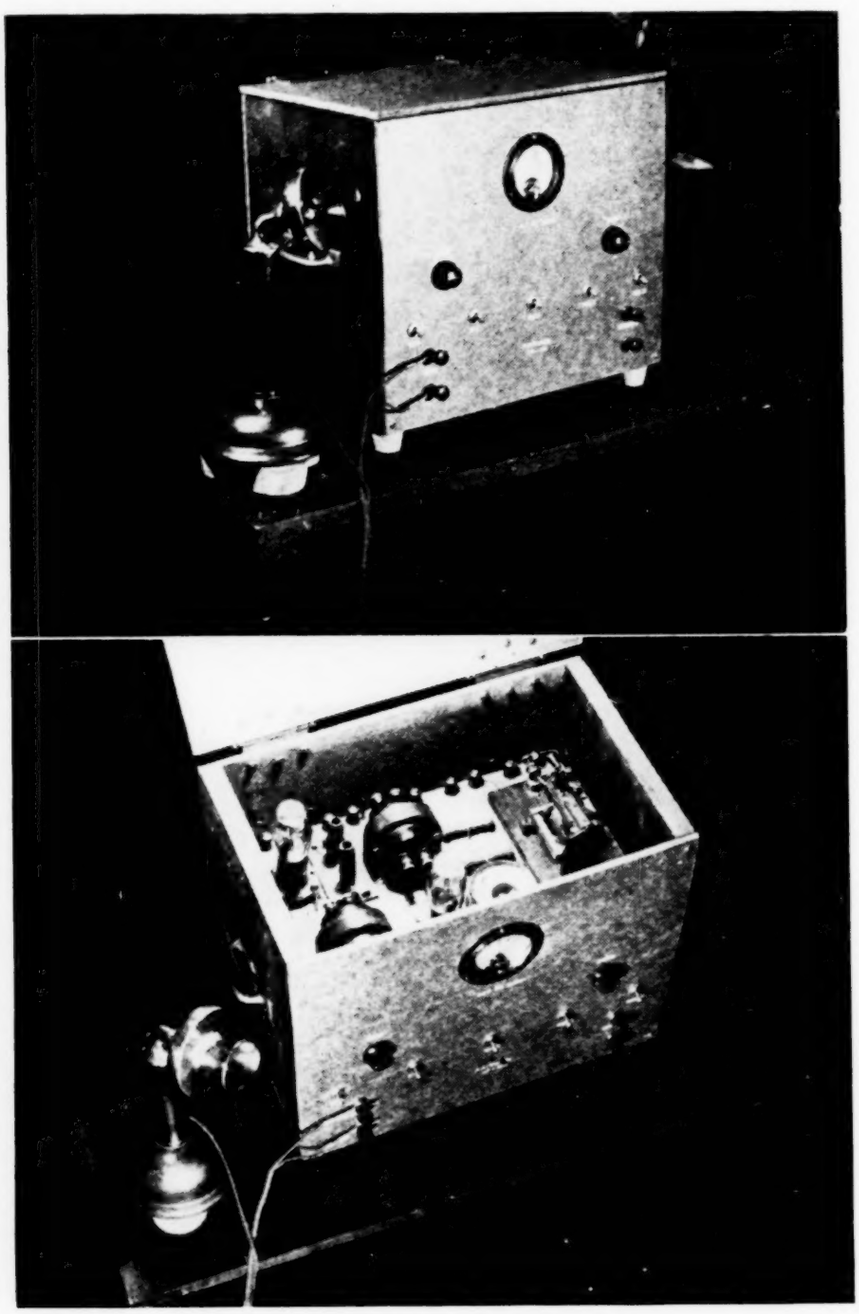
BY JOHN M. FLETCHER AND WALTER C. BOSCH

Departments of Psychology and Physics, Tulane University

It has been well nigh impossible to carry through a consecutive set of reaction experiments from the simple manual response to a sensory stimulus to a verbal response to a verbal stimulus, because of the unsatisfactoriness of the voice keys which one finds on the market. A number of attempts, with the help of a very capable mechanician, to correct the mechanical difficulties of the old type of voice key have so far failed. The power of the voice itself in normal responses has proved to be insufficient to actuate the key so as to make or break a circuit. Very delicate adjustments were found to be required even for explosive consonantal sounds, adjustments so delicate that students were constantly liable to get them out of order. No mechanical apparatus could be constructed which would respond to an open vowel sound. A pooling of ideas of the Departments of Physics and Psychology has resulted in the construction of an apparatus utilizing electronic equipment which has proved highly satisfactory during the past session. This apparatus can be easily duplicated. In the hope that it may be useful to those who have had difficulties similar to our own, a brief description is submitted herein.

Our voice key consists of a microphone connected to controlled vacuum tube amplifier and rectifier circuits which operate sensitive relays. The thermionic tubes, microphone and relays require currents measured in milliamperes, hence small batteries will give good service over a long period. The equipment is assembled in a compact boxed unit as shown in Fig. 1*A*. The box, made of Masonite on a wood frame, is 12.5 in × 15 in × 9.5 in. The box front serves as a panel for the circuit controls, meter, and microphone and output

binding posts. All controls are labeled. Batteries are stored in a bottom compartment and tubes, relays and other circuit elements are mounted and wired on a shelf directly above this



A

B

FIG. 1. Two views of the voice key.

compartment. The back of the box is removable so that batteries may be replaced or repairs made. As shown in Fig. 1*B* the box top is hinged so that the relays may be easily adjusted.

The circuits and circuit elements shown in the connections diagram (Fig. 2) have the following functions and character-

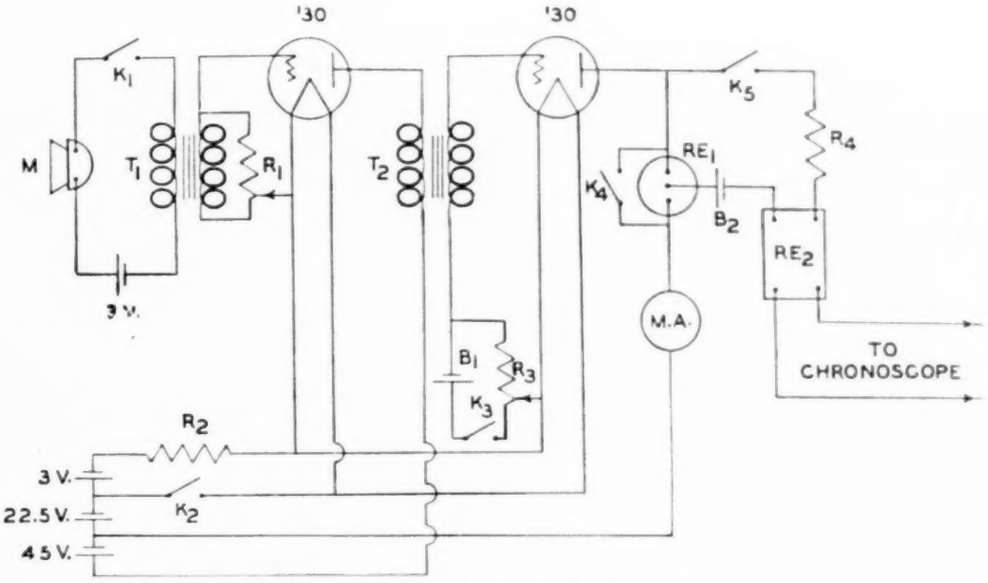


FIG. 2. Voice key circuit diagram.

istics. The thermionic tubes are of the '30 type and resistance R_2 fixes filament currents at the proper value. Microphone M is a 100 ohm single button type requiring 10 milliamperes. Transformer T_1 couples the microphone into the amplifier stage. The input, and hence the sensitivity, is smoothly controlled from zero level by means of the 500,000 ohm potentiometer R_1. The knob for this potentiometer is mounted to the left of the control panel (see Fig. 1*A*). Transformer T_2 couples the amplifier into the rectifier stage. A rectifier is necessary so that a unidirectional current may be sent through RE_1, a sensitive, fast moving Weston model 634 relay of the moving coil type. To close its contacts, the plate current of the rectifier tube is set at zero by means of a negative bias supplied by B_1, a small 4.5 volt battery, connected across the 3000 ohm potentiometer R_3. This operation, controlled by a knob on the right side of the instrument panel, also adjusts the vacuum tube stage to act as an efficient rectifier. The Weston model 375 galvanometer M.A. has two functions. It is used in setting the rectifier plate current to zero, and its reading when the microphone is spoken into indicates the sensitivity of the circuit. Operation of RE_1 controls the power relay RE_2 which keys the chronoscope or

other controlled circuit. RE_2, designed to work with RE_1, is fast moving; B_2 furnishes its potential and R_4 fixes its current at 10 milliamperes. All circuits are provided with toggle switches K_1, K_2 etc. K_4 short circuits the sensitive control relay when the circuit is being adjusted to proper operating conditions. AC battery is used for the microphone circuit, No. 6 dry cells furnish filament current and the higher voltage sources are No. 762 Eveready portable B batteries.

When the instrument is in use, the microphone, attached to a flexible cord, is put at a position convenient for the experiment and the boxed unit is placed near and connected to the chronoscope or other controlled circuit. To adjust the circuit to proper operating conditions, all switches are turned on and potentiometer R_3 is adjusted until the meter M.A. reads zero. The sensitivity control R_1 is set at the desired level and then K_4 is switched off. Once having set R_1 and R_3, putting the voice key into service becomes merely a matter of manipulating the switches.

The sequence of operation in the circuit is as follows. When the microphone is spoken into, the weak audio frequency currents are amplified in the first vacuum tube stage. In the rectifier stage the pulsating audio currents are made unidirectional and a strong torque is exerted on the moving coil of control relay RE_1. The operation of this relay keys the power relay RE_2.

The demonstrated advantages of this type of apparatus over the old, mechanically actuated voice key are (1) ease and stability of adjustment, (2) reliability of operation at normal voice levels, and (3) possibility of remote control.

The approximate cost of the equipment is as follows:

Relays	$12.00
Microphone	5.00
Transformers	4.00
Meter	7.50
Vacuum tubes	1.00
Potentiometers	1.50
Switches	1.00
Batteries	4.50
Box and wiring	3.00
Total	$39.50

(Manuscript received August 10, 1937)